Numerical prediction of the pullout behavior of geosynthetics

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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.

1 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 environmental and boundary conditions are fully controlled. 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 (Beech, 1987, Ochiai et al, 1996; Sieira et al, 2009) and numerical (Sobhi & Wu, 1996; Becker, 2006; Ferreira, 2009) 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 (Espinoza, 2000). 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).

2 ANALYSES

2.1 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 GA e GB. Both are nonwoven needle-punched geotextiles and their main physical and mechanical 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 dimension samples (22.9cm in diameter), under different confining stress levels. The tests provided friction angle (\(\phi\)) and cohesion (c') equal to 37° and 10kPa, respectively.
Table 1. Geotextile properties (Espinoza, 2000)

<table>
<thead>
<tr>
<th>Property</th>
<th>Geo</th>
<th>Textile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal resistance (kN/m)</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Transverse resistance (kN/m)</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Elongation at failure (%)</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>2.3</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Pullout tests were carried out in large dimension equipment (1m x 1m x 0.6m), 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.

2.2 Numerical model

The geometry, boundary conditions, and load systems, adopted in the numerical analyses, are summarized in Figure 2. The test box is 0.60m high and 1.0m long. The box walls were represented by rigid plates. The geotextile length was equal to 0.90m. The confining stress was simulated by an 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 movement of geotextile.

The geotextile was simulated by an element presenting tensile resistance only. Table 2 summarizes the geotextiles and rigid walls parameters. The axial stiffness (EA) of geotextiles GA and GB were defined from tensile tests results. Steel properties were used to compute the stiffness of box walls, considering a wall thickness equal to 2.0mm.

Table 2. Constitutive models and parameters (Ferreira, 2009)

<table>
<thead>
<tr>
<th>Material</th>
<th>Constitutive model</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotextile GA</td>
<td>Linear and elastic</td>
<td>EA = 550kN/m</td>
</tr>
<tr>
<td>Geotextile GB</td>
<td>Linear and elastic</td>
<td>EA = 1000kN/m</td>
</tr>
<tr>
<td>Rigid walls</td>
<td>Linear and elastic</td>
<td>EA = 210MN/m; e = 0.002; ν = 0.15</td>
</tr>
</tbody>
</table>

Soil-geotextile behavior was simulated by prescribing an interface element above and below the interface contact. This element minimizes the shear strength parameters of the soil adjacent to the reinforcement, by applying a correction factor (R_{inter}), according to the following expressions:

\[
R_{inter} = \begin{cases} 
0.8 & \tan \phi \leq 1.0 \\
1.0 & \tan \phi > 1.0 
\end{cases}
\]

where: \(c_a\) = interface adhesion; \(c\) = soil cohesion; \(\phi\) = soil friction angle \(\delta\) = angle de atrito do solo.

In the present study, interface elements were prescribed not only at the soil-geotextile contacts but also at the front wall contact to simulate internal lubrication. Correction factors (R_{inter}) were defined according to experimental data provided by Espinoza (2000), as shown in Table 3.

At the contact between soil sample and front wall, R_{inter} was defined according to Palmeira & Dias (2007) indicating a light lubrication.

Table 3. Interface parameters

<table>
<thead>
<tr>
<th>Interface</th>
<th>R_{inter}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil-Geotextile GA</td>
<td>0.71</td>
</tr>
<tr>
<td>Soil-Geotextile GB</td>
<td>0.93</td>
</tr>
<tr>
<td>Soil-Front wall</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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. Soil parameters are presented in Table 4, and were depicted from the triaxial drained tests (Espinoza, 2000).

Figure 1. Pullout test instrumentation (Espinoza, 2000)

Figure 2. Numerical model (Ferreira, 2009)

Figure 3. Load A and Load B
Table 4. Geotechnical parameters of the sandy soil

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformability modulus corresponding to 50% failure ($E_{50}$)</td>
<td>35,000kN/m²</td>
</tr>
<tr>
<td>Oedometric modulus ($E_{oed}$)</td>
<td>28,000kN/m²</td>
</tr>
<tr>
<td>Unloading modulus ($E_{ur}$)</td>
<td>105,000kN/m²</td>
</tr>
<tr>
<td>HS model exponential parameter (m)</td>
<td>0.5</td>
</tr>
<tr>
<td>Cohesion (c’)</td>
<td>16kPa</td>
</tr>
<tr>
<td>Friction angle ($\phi$)</td>
<td>37º</td>
</tr>
<tr>
<td>Dilatancy angle ($\psi$)</td>
<td>7º</td>
</tr>
<tr>
<td>Specific weight ($\gamma$)</td>
<td>19.79kN/m³</td>
</tr>
</tbody>
</table>

3 RESULTS DISCUSSION

Figure 3 compares the experimental results with numerical prediction of GA pullout test, under 25kPa of confinement. The results (Figure 3a) show a good agreement at the rear end of the geotextile. According to Espinoza (2000), the strain-gage located 200mm from the front edge of the box was damaged during the test and the SG3 (400mm from the front end) presented malfunction.

![Figure 3](image)

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 GB 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).

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 GB. Additionally, the linear and elastic constitutive model does not incorporate an ultimate load.

![Figure 4](image)
3.1 Influence of geotextile stiffness

Geotextiles GA and GB 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 50kPa of confinement. It is interesting to note that experimental data with geotextile GA 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 GB present lower strains due to its higher stiffness. Moreover, it is observed a good agreement between both approaches.

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

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

4 CONCLUSIONS

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 predictions proved to be satisfactory and consistent with the experimental results. Besides they may be used as a design tool to help engineers to reduce the uncertainties in defining the anchorage length of geotextiles.

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REFERENCES


