Centrifuge Modelling of Soil Reinforced Systems with Geogrids

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ABSTRACT: In this paper the behaviour of wall and a steep slope reinforced with geogrids will be analysed based on the results of centrifuge modelling. The centrifuge apparatus will be described, as well as, the reinforced systems to be modelled. Physical and mechanical characteristics of the materials will be referred, as well as, models construction procedures and adopted control techniques. Test and monitoring procedures will be described and the obtained results will be analysed. The deformations measured in the centrifuge tests will be compared with the registered by site monitoring and with that calculated by numerical modelling.

1 INTRODUCTION

The main target of this paper is to enhance the potential of centrifuge physical modelling of soil reinforced systems with geosynthetics. To achieve this objective the deformation data of centrifuge tests are compared with those obtained numerically and of the site observation of the behaviour of a reinforced slope. Two reinforced systems were considered: i) a geosynthetic reinforced wall; ii) a geosynthetic reinforced slope, with 60° slope angle.

The wall has a height of 6m and was analysed by the finite elements method by Ho (1993), and later modelled using the FLAC software (version 3.00) by Bathurst and Hatami (1998) and by Mendonça (2004). The slope was constructed and monitored on a Portuguese highway (Régua-Reconcos) has a height of 20m and was modelled using the FLAC software (version 4.00) by Mendonça (2004). Figures 1 and 2 present, schematically, the reinforced wall and the reinforced slope, respectively.

Figure 1. Reinforced wall - wall finite element mesh.
2 CENTRIFUGE APPARATUS

The centrifuge apparatus used (Figure 3) is composed by a metallic pyramidal structure, rigidly connected to the chamber threshold, a swivel-arm and an engine. The swivel-arm has at one end the bascule basket, where the model is placed, and at the other end an adjustable deadweight to the set equilibrium.

The mean turning radius, at the assembly platform, is 1.80m, and at the basket geometric centre the turning radius is 1.55m. The maximum size of the model is 500mm x 700mm x 500mm, and its maximum weight depends on the acceleration – 4kN for accelerations lower than 100g, decreasing to 2kN for an acceleration of 200g (corresponding to a maximum rotational speed of 345rpm).

In order to see the behaviour of the model during the centrifuge test there is a video camera in the bascule basket connected the command room.

3 CENTRIFUGE MODELLING OF GEOGRIDS SOIL REINFORCED SYSTEMS

3.1 Soil

In the tests a pure white Fontainebleau sand (Ref. sable NE 25/34) was used. The grain size distribution and the relevant characteristics of the sand are presented in Figure 4 and Table 1, respectively.
The soil was placed by the dry shower technique, using a sand shower composed by a fixed reservoir and a bascule hopper, moving automatically over the container to fill.

### 3.2 Reinforcements

The plastic meshes used to simulate the reinforcements are presented in Figure 5. The selection of those meshes was based on their different apertures size and stiffness.

![Reinforcement meshes](image)

**Figure 5.** Reinforcement meshes: a) mesh 1; b) mesh 2.

The tensile behaviour of the meshes was defined by performing tensile tests according EN ISO 10319. Figure 6 presents the load-extension curves on the machine direction (MD) and on the cross machine direction (CMD) for both materials.

The results show a similar behaviour in both directions for mesh 1 and a distinct behaviour in the two directions for mesh 2. The load-extension behaviour of the two meshes is different, being that of mesh 2 more brittle. The extension for the maximum load is similar for both meshes and in the two directions tested.
3.3 Test procedures and monitoring

Finished the placement of the soil, by sand shower, the transparent box (liner) was weighted and carefully placed in the metallic rectangular container. Then, the set was transported to the centrifuge apparatus platform, whose arm was previously balanced to the total weight to ship. Two different phases of preparation are presented in Figure 7.

After the confirmation of the correct location of the shipped set, displacements transducer cables were connected to the data acquisition system. Simultaneously, the video camera and the fluorescent lamp were placed in order to allow the visual observation of the model during the test. Finally, the centrifuge chamber was inspected, visually, and the test started.

To the execution of the face, during the construction of the models, plastic elements of variable thickness were used. These elements were placed in the anticipated sand layer, just previously the sand shower. After the model construction and the placement of the liner in the metallic container, the plastic elements were removed.

Two transducers of 25mm were used to measure the deformations of the face of the model, one of them (LVDT) located near the top, and the other (potentiometer) positioned near the base. Both transducers were hold up by a metallic beam positioned over the container. The reading points were materialized by two semi-rigid marks glued to the structure face.

The data acquisition and control was done by specific software by which displacement-time relations can be obtained in real time.

3.4 Test program

Table 2 shows the test program followed. In the tests 1 and 2 mesh 1 was used as reinforcements, and in tests 3 and 4 the reinforcements were simulated by mesh 2.
Table 2. Test program.

<table>
<thead>
<tr>
<th>Test</th>
<th>Prototype</th>
<th>Model</th>
<th>N</th>
<th>rpm*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope angle (°)</td>
<td>Height (m)</td>
<td>Reinforcement length (m)</td>
<td>Slope angle (°)</td>
</tr>
<tr>
<td>1</td>
<td>90.0</td>
<td>6.0</td>
<td>4.5</td>
<td>90.0</td>
</tr>
<tr>
<td>2</td>
<td>60.0</td>
<td>20.0</td>
<td>12.0</td>
<td>60.0</td>
</tr>
<tr>
<td>3</td>
<td>90.0</td>
<td>6.0</td>
<td>4.5</td>
<td>90.0</td>
</tr>
<tr>
<td>4</td>
<td>60.0</td>
<td>20.0</td>
<td>12.0</td>
<td>60.0</td>
</tr>
</tbody>
</table>

* Centrifuge apparatus used: $R=1.80m$, $h_m=0.28$; $R_c=1.52m$; $g=9.81m/s^2$.

Tests 1 and 3 model the reinforced wall, and test 2 and 4 model the reinforced slope (see 1). Figure 8 presents, schematically, the assembly of the tested models. Figure 9 shows one of the models in the centrifuge apparatus.

Figure 8. Tested models: a) test 1; b) test 2; c) test 3; d) test 4.

Figure 9. Model placed in the apparatus.
3.5 Test results

Finished the centrifuge, the models were removed from the apparatus and their deformation compared with the mesh drawn in the face liner. Then, the models were saturated, cut and their behaviour analysed.

Table 3 presents the displacements registered in the tests 1 and 2, and Figure 10 shows the results obtained in tests 3 and 4.

Only the model of test 1 fails, the other 3 deformed in an acceptable range until the end of the test, which was determined by the maximum acceleration allowable by the apparatus balance limit.

In the Figure 11a the face displacements of the wall, with a height of 6m, obtained numerically and in the tests 1 and 3 are compared. It can be seen, that the results from the numerical and centrifuge modelling are very similar for test 1. However, for the tests 3 the displacements measured in the centrifuge test are much greater than that registered in the numerical modelling.

Table 3. Results of centrifuge tests 1 and 2.

<table>
<thead>
<tr>
<th>Test</th>
<th>Similarity</th>
<th>Displacements (cm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Rpm</td>
<td>1/2 height</td>
</tr>
<tr>
<td>1 (wall)</td>
<td>33</td>
<td>140</td>
<td>2.00</td>
</tr>
<tr>
<td>2 (slope)</td>
<td>100</td>
<td>245</td>
<td>0.80</td>
</tr>
</tbody>
</table>

![Figure 10. Centrifuge tests results: a) test 3; b) test 4.](image)

![Figure 11. Wall face displacements modelled numerically and physically (centrifuge): a) tests 1 and 3; b) tests 2 and 4.](image)
It must be emphasized that model 1 has 5 reinforcement levels, simulated by mesh 1, and model 3 has 6 reinforcement levels (as the prototype) simulated by mesh 2. On the contrary to what happened in the centrifuge modelling of test 1, failure did not occur on the numerical modelling.

In Figure 11b the slope face displacement monitored in site and defined numerically and by centrifuge tests (tests 2 and 4) are compared.

It can be seen that numerical and centrifuge tests results for model 2 (5 reinforcement levels – mesh 1) are similar in the upper part of the slope. In the lower part of the slope the results from both modellings diverge.

The centrifuge tests results of model 4 (10 reinforcement levels – mesh 2) show a similar trend as the site monitoring, although with greater values. The displacements observed on the numerical simulation are much greater than that obtained in the other two approaches, especially in the lower part of the slope.

The centrifuge tests results reveal the huge relevance of the material used to simulate the reinforcements. In fact, although mesh 2 has higher initial stiffness than mesh 1 (Figure 12a), the secant stiffness of mesh 2 for different values of extension (namely 10%) is lower than that of mesh 1 (Figure 12b). For this reason, the simulation of the reinforcements with mesh 1 leads to higher efficacy in the restriction of face displacements during the centrifuge tests.

![Graph a) and b)](image)

Figure 12. Machine direction tensile stiffness of meshes 1 and 2: a) initial stiffness; b) secant stiffness at 10% extension.

It must be enhanced that centrifuge modelling does not consider the influence on the displacements of the incremental construction of the slope. This circumstance justifies, in part, the difference observed between numerical results and centrifuge results for model 2 in the lower part of the slope. On the other hand, the lower values of monitored displacements can be due, partially, to the impossibility to register them since the beginning of the slope construction and, in part, to the methodology used to measure them (Mendonça et al., 2003).

4 CONCLUSIONS

The research developed is a preliminary evaluation of the potential of the centrifuge modelling of walls and slopes reinforced with geosynthetics and not a rigorous approach to that technique. However, based on the obtained results it seems possible to put forward some conclusions, namely:

i. The load-extension behaviour of the meshes used to simulate the reinforcements have huge relevance on the results, specially in what concerns the tensile stiffness for small extensions;

ii. The use of centrifuge modelling to study the behaviour of reinforced structures propped constructed has a huge field of application, however, difficulties in modelling the effects of incremental construction of walls and slopes limit the application of centrifuge modelling to that structures;

iii. Centrifuge modelling of reinforced slopes does not show failure, even for high values of acceleration;

iv. Although there is need to develop deep and rigorous research on the centrifuge modelling of reinforced structures constructed incrementally, centrifuge modelling shows a remarkable potential to the study of the behaviour of soil reinforced systems with geosynthetics.
ACKNOWLEDGMENTS

The authors would like to thank to LNEC the collaboration to the performance of the centrifuge tests
The authors would like to thank the financial support and patronage of FCT, POCTI and of FEDER, Re-

REFERENCES

University of Western Ontario, London, Canada, 408p.
Mendonça, A. (2004). “Different methodologies to study the behaviour of soil reinforced systems with
Portuguese).