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Pull-out tests for the assessment of soil-geogrids interaction – Influence of some mechanical and physical parameters

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ABSTRACT: Testing equipment and procedures, specimen preparation are presented for pull-out tests for geogrids in granular soils. The interaction between a well graded sand and a HDPE uniaxial grid is studied in a pull-out box with 1.53m length, 1.0m width and 0.8m height. The influence of the displacement rate, soil density and specimen length on the pull-out force of the grid is discussed by analysing the results of the tests.

1 INTRODUCTION

The necessity of carrying out tests on geosynthetics to study their suitability for a particular application is becoming more and more important as the variety of geosynthetics in the international market and their use in geotechnical works has been increasing in the last years.

The large scattering of the published pull-out tests results comes from the utilization of: different testing equipment associated to distinct boundary effects; different testing procedures; different schemes of placement and compaction of the soil; etc. (Juran *et al*., 1988).

The increasing application of geosynthetics in soil reinforcement needs the development of standard methods of evaluation of the in-soil mechanical characteristics of the geosynthetics and of its interfaces with the soil.

With the objective of obtaining additional information about the mechanical behaviour of the soil-geosynthetics interfaces and of the influence on it of some mechanical and physical parameters, the role of the displacement rate, soil density and specimen length in the granular soil-geogrid interface behaviour will be studied in this paper by analysing the results of pull-out tests.

2 EQUIPMENT,MATERIAL AND PROCEDURES

The pull-out box used to study soil-geogrid interaction is represented in Fig.1 and has internally 1.53m length, 1.00m width and 0.80m height. The use of a box with large dimensions aimed at minimizing the influence of the lateral, base and top boundaries (Ladeira, 1995). The reduction of the influence of the top boundary and the uniform distribution of the applied vertical stresses are achieved by placing over the top of the soil a smooth neoprene slab with 0.025m thickness. To reduce the influence of the front wall, a steel sleeve is used with 0.20m length inside the box.

At the mid-height there are two apertures (one in the front wall and another in the back wall of the box) to permit the pull-out of the reinforcement and the passage of the inextensible wires for the measurement of the displacements in different points along the length of the inclusion.

The pull-out force is transmitted to the specimen by a clamp and is obtained by an hydraulic system which permits the application of constant displacement rate.

The confinement stress is applied by placing ten small cylindrical masses on the top of the box. The pull-out force is measured by a load cell and the confinement stress by a pressure cell located between one of the ten cylindres and the wood plate placed below. The frontal displacement and the displacements along the length of the reinforcement are measured by six linear potentiometers. The results are registed by an automatic data acquisition system.

It is important to note the relevance of the measurement of the displacements along the reinforcement when it is extensible as is the case of the geosynthetics. In fact, in this type of inclusions the movement during pull-out has two components, one corresponding to friction strain on the soil-reinforcement interface and another due to the

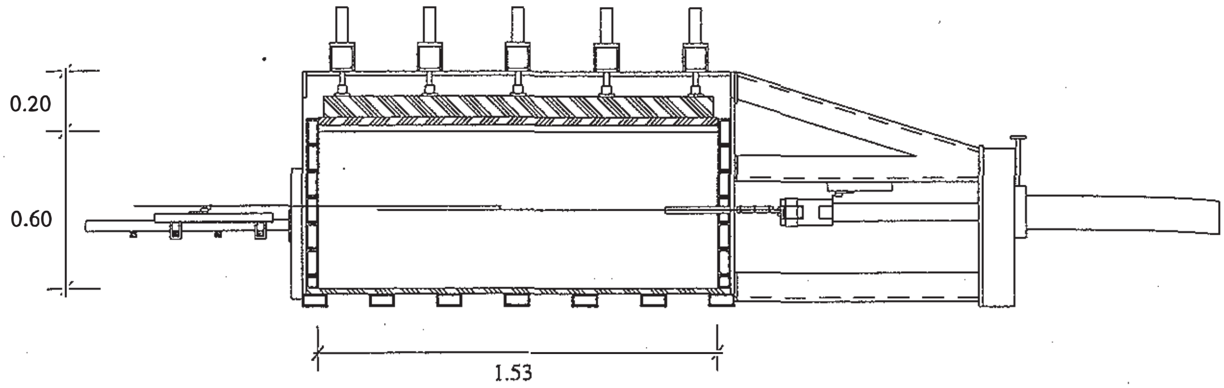


Fig. 1. Pull-out box (schematic representation).

elongation of the inclusion, this one being more significative in the frontal part of the specimen.

The possibility of knowing separately each one of the components of the movement permits a better understanding of the soil-geosynthetic interaction phenomena.

The soil used in the tests is granular, its granulometric curve is represented in Fig.2. The sand has an effective diameter, D_{10}, of 0.35mm and a maximum and minimum density of 18.9kN/m^3 and 16.1 kN/m^3, respectively. The residual friction angle is 35.5° for the soil densities and confinement stress tested.

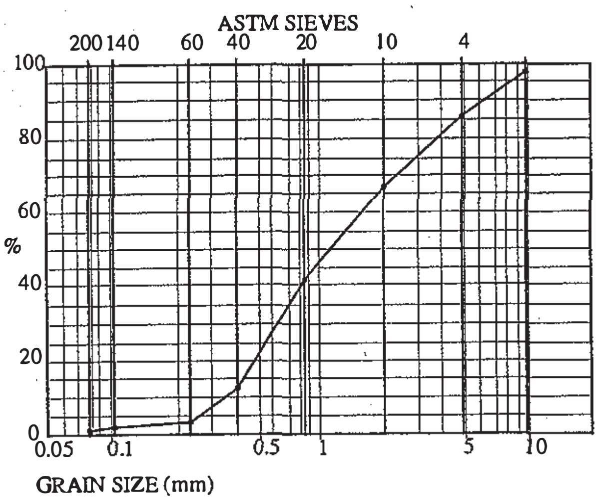


Fig. 2. Granulometric curve of the soil.

The geosynthetic tested was a HDPE uniaxial geogrid with 55kN/m of tensile strength. The specimen had 0.33m width and 0.96m confined length at the beginning of the test. The confinement pressure used in the tests was of 46.7 kPa at the level of the reinforcement.

The sand was placed in 0.15m thick layers, each one being levelled and compacted to the required density by an electric vibratory hammer.

The sand is poured into the box from a constant height, of 0.40m, in relation to the last compacted level.

After compaction the soil density is controlled by a gammadensimeter. When the sleeve level is reached the reinforcement is placed over the compacted soil and introduced inside the sleeve positioned in the front wall with a 0.20m length inside the box. The geogrid is then fixed to a clamp placed outside the box. The inextensible wires used to measure the displacements along the reinforcement are then placed and connected to the linear potentiometers placed outside at the back of the box (see Fig.1). The potentiometer that measures the frontal displacement of the inclusion is placed at the front of the box. Finally, two 0.15m thickness soil layers are placed, levelled and compacted. At the end the geogrid is positioned at the middle of a 0.60m height of sand.

Table 1. Testing program

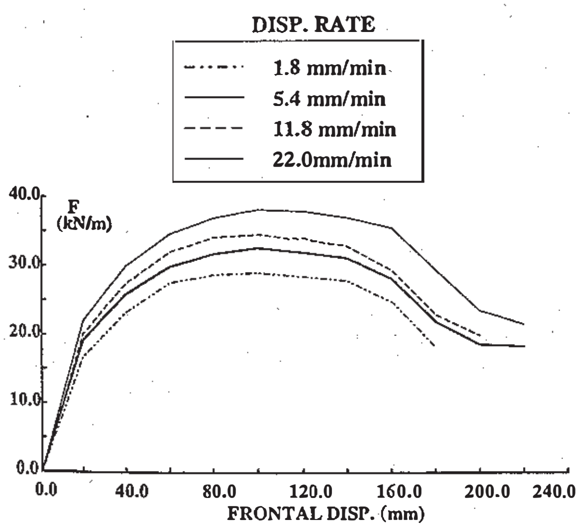
Parameter under study	Displac. rate (mm/min)	Soil density (kN/m^3)	Specimen length (m)
Displacement rate	1.8 5.4 11.8 22.0	17.5	0.96
Soil density	5.4	17.5 18.5	0.96
Specimen length	5.4	17.5	0.80 0.96 1.12
	5.4	18.5	0.34 0.60 0.96

The test program carried out to study the influence of the displacement rate, the soil density and the specimen length on the pull-out behaviour of a geogrid placed in a granular soil with the referred characteristics is indicated in Table 1.

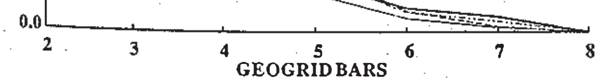
3 ANALYSIS OF RESULTS

3.1 *Influence of the displacement rate*

The influence of the displacement rate on the pull-out force of the geogrid under study is shown in Fig.3a. It can be seen that the pull-out force of the inclusion increases with the displacement rate. When the displacement rate changes from 1.8mm/min to 22mm/min the pull-out force increases by 30%, the increase is of about 10% when the displacement rate changes from 1.8mm/min to 5.4mm/min.



a)



b)

Fig. 3. Influence of the displacement rate on: a) pull-out force; b) the deformation of the geogrid for the maximum pull-out force.

The increase in the displacement rate leads to a reduction in the frontal displacement necessary to mobilize the same pull-out force. On the other hand, the displacement along the reinforcement induced by strain shows tendency to reduce as the displacement rate increases (Fig.3b). In fact, the maximum displacement by strain of the reinforcement decreases about 14% when the displacement rate increases from 1.8mm/min to 11.8mm/min.

The observed behaviour leads to the conclusion that the increase in the pull-out force with the displacement rate results, at least, partially, from the increment in the reinforcement stiffness with the velocity and not from the increase of the mobilized tangential stresses in the soil-reinforcement interface. Another factor responsible for the increase of the pull-out force with the displacement rate is the reduction of the soil capacity to rearrange with the increment of the velocity.

Defining the adherence factor as:

$$f = \frac{\tau}{\sigma_n tg\phi} \quad (1)$$

where τ and σ_n are the tangential and normal stresses in the interface, respectively, and ϕ is the friction angle of the soil, it can be seen in Table 2 the influence of the displacement rate on the pull-out force and on the adherence factor. In fact, the pull-out force and the adherence factor change from 28.9kN/m to 38.0kN/m and from 0.506 to 0.677, respectively, when the displacement rate increases from 1.8mm/min to 22mm/min.

Table 2. Influence of the displacement rate

Displacement rate (mm/min)	Maximum pull-out force (kN/m)	Adherence factor f
1.8	28.9	0.506
5.4	32.2	0.564
11.8	34.6	0.616
22.0	38.0	0.677

From the results it can be concluded that:

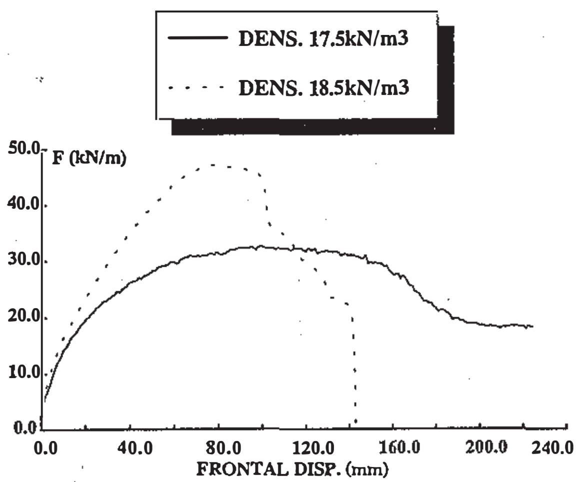
1. the increase in the displacement rate leads to the increase of the pull-out force and of the adherence factor, although the displacements by strain of the inclusion show tendency to reduce;
2. the increase in the pull-out force and in the adherence factor result from the increment in the soil-reinforcement stiffness and from the reduction

in the capacity of rearrangement of the soil grains with the increase of the test velocity.

3.2 *Influence of the soil density*

The density of granular soils is determinant to their strength and deformability. The resistance of soil-reinforcement interfaces is also highly influenced by soil density.

To study the influence of this parameter in the pull-out force of the geogrid under study tests were carried out with soil densities of 17.5 kN/m^3 and 18.5 kN/m^3. The other test conditions are indicated in Table 1.



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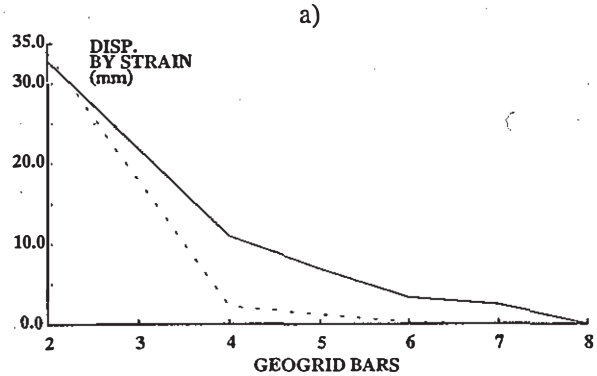

b)

Fig. 4. Influence of the soil density on: a) the pull-out force; b) the deformation of the geogrid for the maximum pull-out force.

The influence of the soil density in the pull-out response of the tested geogrid is shown in Fig.4. It can be seen that the soil density increases the pull-out force of the geogrid (Fig.4a). In fact, for the lower soil density tested the pull-out force of the geogrid measured was 32.2 kN/m with a frontal displacement of 92.7mm and for the highest soil density used the geogrid fails by tensile rupture at a frontal displacement of 74.4mm.

In what concerns the adherence factor of the soil-geogrid interface, it increases from 0.564 to 0.793 when the soil density changes from 17.5 kN/m^3 to 18.5 kN/m^3.

In general, it can be said that the increase in soil density leads to greater soil and soil-inclusion shear resistance. The displacement of the geogrid reduces, increasing the interface stiffness modulus and the pull-out force.

As the soil density increases the length of adherence reduces. In fact, for the higher soil density tested, only one third of the inclusion length contributes for resistance (Fig.4b).

3.3 *Influence of specimen length*

The interest of the study of the influence of the specimen length is the definition of the relation between the dimensions of the apparatus and of the specimen in order to minimize the influence of the lateral boundaries in the results of pull-out tests.

This relation is difficult to define because it depends, not only, on the dimensions of the equipment, but also, on factors such as: the characteristics of the inclusion; density and type of soil; confinement pressure; etc.

The tests carried out to study the influence of the geogrid length are presented in Table 1. It was decided to study the influence of the geogrid length for two different densities, because this parameter affects the length of reinforcement that contributes for the interface resistance, as it can be seen in 3.2.

Fig. 5a represents the frontal displacement of the inclusion versus pull-out force for the three lengths (0.80m, 0.96m, 1.12m) tested in the loose soil (17.5 kN/m^3). It can be seen that in qualitative terms the results are similar for the three tests, but not in quantitative terms.

The maximum pull-out force (Fig.5) increases from 15.3 kN/m to 35.6 kN/m when the specimen length changes from 0.80m to 1.12m. This behaviour is due, not only to the influence of lateral boundaries, but also to the fact that there is no significative increase in the interface resistance when the length of the inclusion is greater than a certain value (Lopes, 1992).

The adherence factor increases significatively when the geogrid length increases from 0.80 to 0.96m; when this parameter changes from 0.96 to 1.12m the adherence factor remains practicely constant (see Table 3).

From the study undertaken it can be concluded that for the apparatus used the optimum length of the specimen (in the sense that it does not affect the test results) is about 1.00m.

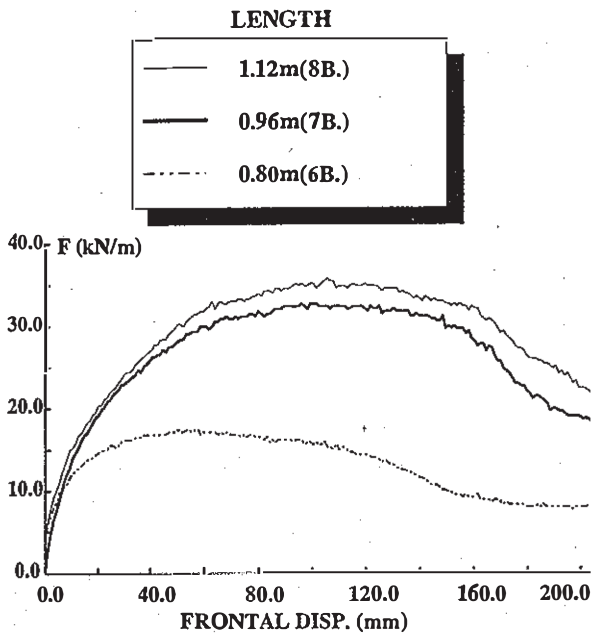

Fig. 5. Influence of the specimen length on the behaviour of pull-out force versus frontal displacement (loose soil - γ=17.5 kN/m^3).

Table 3. Influence of the specimen length (loose soil)

Specimen length (m)	Maximum pull-out force (kN/m)	Adherence factor f
0.80	17.3	0.353
0.96	32.2	0.564
1.12	35.6	0.532

The study of the influence of the specimen length in dense soil showed that for all the three lengths tested the specimen failed by lack of tensile strength and not by lack of adherence. The frontal displacement at rupture reduces when the geogrid length decreases. The maximum pull-out force decreases lightly, as well as the adherence factor, when the specimen length increases (see Fig. 6 and Table 4). It must be noted that the adherence factor can be greater than the value measured in the tests because the samples did not fail by lack of adherence.

The observed behaviour is due to the influence of the frontal wall. In fact, this influence is greater in dense soils and is more important in the area of the specimen localized near the frontal wall. So, in short specimens the influence of the frontal wall can be extended to the whole specimen increasing the pull-out force and the adherence factor.

Table 4. Influence of the specimen length (dense soil)

Specimen length (m)	Maximum pull-out force (kN/m)	Adherence factor f
0.34	50.2	0.853
0.65	48.9	0.837
0.96	47.1	0.793

The reduction of the length of the reinforcement makes easy its pulling-out, as it can be seen by the increase in the displacement of the posterior bar of the geogrid with its length reduction (0.0mm, 1.1mm, 3.8mm, respectively, for geogrids lengths of 0.96m, 0.65m and 0.34m). In the tests carried out the effective anchorage of the inclusion due to the soil density inhibits the failure by lack of adherence, failing the geogrid by lack of tensile strength in the unconfined part of the sample.

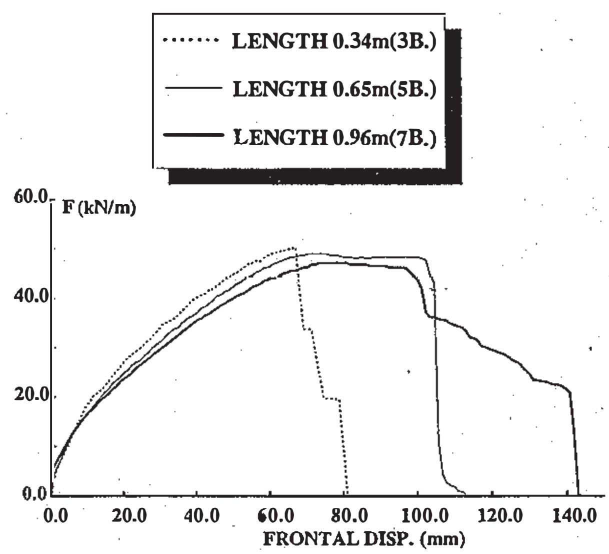

Fig. 6. Influence of the specimen length on the behaviour pull-out force versus frontal displacement (dense soil - γ=18.5 kN/m^3).

4 CONCLUSIONS

The study of the influence of the displacement rate, soil density and specimen length on the pull-out force of a uniaxial geogrid in a granular soil leads to the following major conclusions:

1. the increment of the pull-out force and of the adherence factor when the displacement rate increases result from the increment of the soil-inclusion interface stiffness and from the reduction of the capacity of rearrangement of the soil grains;
2. when the soil density increases the interface stiffness modulus and the pull-out force also increase and the length of adherence reduces;
3. the increment of the interface resistance reduces significatively for specimen lengths over 1.00m.

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