Behavior of geogrids under pullout tests in fine and coarse soils
Comportement de géogrilles sous essais d'arrachement en sols fins et grossiers

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ABSTRACT

This paper presents an analysis of the behavior of geogrids when subjected to pullout tests in the field and in the laboratory. Different types of soils were considered, ranging from silty clay to coarse sand. The field work was associated to a 1700m long, 5m high soil wall reinforced with geogrids. The wall constitutes the upper part of a dike constructed for containing bauxite residues and was constructed using a residual silty-clay. A 2.6m high experimental fill was also constructed for performing 16 large-scale pullout tests. Horizontal loads and displacements were monitored during these pullout tests. In the laboratory, a large dimension pullout apparatus was used for testing the polypropylene and polyester geogrids, which exhibited distinct physical and mechanical stiffness and strength characteristics. The geogrids were instrumented with horizontal displacement gages (tell-tails) and strain gauges, placed on different positions along the grid's length. Silty-clay and sand were used in the experimental program. Conventional laboratory tests were conducted for defining the strength and deformability parameters of both the soil and the geogrid.

RÉSUMÉ

Cet article présente une analyse du comportement des géogrilles soumises aux essais d'arrachement in situ et dans le laboratoire. Différents types de sols ont été considérés, s'étendant de l'argile limoneuse aux sable ou graviers. Les essais sur le terrain ont été associés à un mur de sol de 1700m de longuer et 5m de hauteur, renforcé avec des géogrilles. Le mur constitue la partie supérieure d'une digue construite pour contenir des résidus de bauxite et a été construit en utilisant argile limoneuse résiduel. Un remblai expérimentale avec 2.6m de hauteur a été également construite pour réaliser 16 essais d'arrachement à grande échelle. Des charges et les déplacements horizontaux ont été surveillés pendant ces essais d'arrachement. En laboratoire, un equipement d'arrachement de grandes dimensions a été utilisé pour essayer les géogrilles de polypropylène et de polyester, qui ont montré des caractéristiques physiques et mécaniques de rigidité et de force distinctes. Les geogrids ont été équipés avec des transduteurs de déplacements horizontaux et jauges extensométriques, placés sur différentes positions sur la longueur de la géogrille. Trois matériaux, argile limoneuse et sable ont été employés dans le programme expérimental. Des essais en laboratoire conventionnels ont été effectués pour définir les paramètres de force et de déformabilité du sol et de la géogrille.

Keywords: Geogrids, interface resistance, field and laboratory tests, pullout tests.

1 INTRODUCTION

For many years, reinforced or gravity concrete walls have been designed as retaining structures. However, in cases of high slopes and poor quality foundations, the cost of these structures may become too high. Elias et al (2001) suggest, under these conditions, the use of reinforced soil as being economical and technically appropriate solutions. Reinforced soil walls are fast to build and capable of standing differential settlements.

Geogrid reinforced soil walls are becoming increasingly popular in most countries. Adequate design requires knowledge of the soil-geogrid interface characteristics, with special emphasis for the interface strength parameters. In case of excessive length of geogrids, the design may become too costly. On the other hand, short geogrids may result in a failure by insufficient anchorage length.

The soil type to be used in geogrid reinforced soil structures is also very relevant. Most design criteria are based on frictional characteristics only, with cohesion being disregarded. Clean sandy soils are therefore more common in reinforced soil applications (Elias et al. 2001, Jones 2002, Palmeira 2004). However, in tropical countries, like Brazil, fine weathered residual soils are frequently available at slope sites and their use may become economically attractive.

This paper presents the main results of an investigation on the behavior of geogrids interfacing with different types of soils. Field and laboratory pullout tests were performed on instrumented geogrids. A brief description of the test set-ups and instrumentation is presented in this paper.

2 PULLOUT TESTS

Many researchers have reported on the interaction behavior between soils and geosynthetics from pullout tests: Bonczikewicz et al (1988), Juran and Chen (1988), Bergado et al (1993), Fannin and Raju (1993), Farrag et al (1993), Wilson-Fahmy et al (1994), Chang et al (1995), Lopes and Ladeira

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(1996), Ochiai et al (1996), Bakeer et al (1998a), Bakeer et al (1998b), Alagiyawanna et al (2001), Sugimoto et al (2001), Sayao et al (1999), Sieira (2003). Conclusions from these studies may become impaired by discrepancies in experimental devices, material properties, boundary conditions and specimen dimensions (Sieira et al, 2009).

In most cases, the pullout tests were conducted in sandy soil in the laboratory, using devices with no sleeves for reducing the effect of the frontal wall. The sizes of the laboratory specimens varied considerably, although the length/width ratio was kept within 2.0 to 2.5. Testing details also varied: e.g., the pullout rate was frequently about 1mm/min, but Mallick et al (1996) reported on tests carried out before mid 80's with rates ranging from 0.01 to 20mm/min.

3 EXPERIMENTAL FILL

With the aim of reducing the environmental impact and the construction volume of a tailings disposal area at an aluminum plant in Poços de Caldas, Brazil, a 5m high geogrid reinforced fill was built with a steep external face on top of a 1700m long earth dike.

Due to the high pH of the tailings material (NaOH contaminated sludge), special geogrids were adopted, with a high chemical resistance. The locally available clayey silt was excavated and used. Becker (2006) describes the construction details.

A trial set-up was implemented at the construction site for carrying out field pullout tests (Figure 1). The experimental earth fill was 2.6m high, 3.5m wide and 10.8m long, excluding the end access ramps.

Nine geogrid specimens were placed next to each fill side. The steel tracks were buried and concreted in the foundation ground and tied with steel cables, while the fill layers were compacted.

The experimental earth fill was built with the same soil and the same equipment used for the construction of the dikes and the reinforced wall. A vibratory CA-25roller was used, with manual compaction at the proximities of the side walls.

Compaction specifications were kept identical to the reinforced wall in one half of the fill: water content within -2 to +2% of optimum, and compaction degree within 95% to 100%, relative to standard Proctor.

Twelve geogrid specimens were tested in this "dry" material. The other half of the fill was built with "wet" soil: water content ranging from +2 to +4% of optimum, and minimum compaction degree kept at 95%. Six grid specimens were placed in this half.

This arrangement was planned for evaluating the effect of compaction conditions on the pullout strength, because wet soil was abundant locally.

During construction, eighteen geogrid specimens (1.00 x 0.85m) were placed horizontally at different fill depths. For ensuring uniform vertical stress conditions on the geogrid specimens, the fill was laterally supported by vertical wood platens, held up by vertical train tracks on both faces sides.

The geogrid used in these field tests, herein named "55B", presents tensile strength of 55kN/m with 5% elongation at failure and nominal stiffness of 700kN/m. The mechanical properties of the geogrid were obtained by standard testing of multiple layers of multiple geogrid ribs in tension (ASTM D6637-01).

The main properties of the soil used in the experimental fill can be found in Table 2. Soil parameters were obtained by direct shear tests on block samples after field compaction.

Table 2 . Strength parameters from direct shear tests (Becker, 2006).

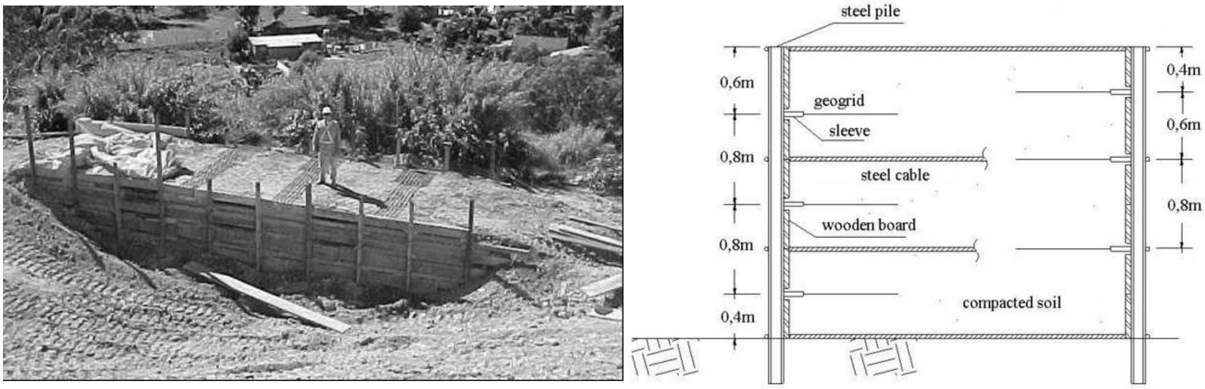
Fill region	Test condition	Friction angle (°)	Cohesion (kPa)
"dry side"	As compacted	42.6	12.4
"dry side"	Submerged	34.0	6.0
"wet side"	As compacted	34.5	5.9

4 LABORATORY TESTS

The pullout laboratory tests were carried out in a large size shear device at the Cedex, Spain. The rigid shear box was made of aluminum, with inner dimensions of 1.0 x 1.0m (horizontal) and total height of 1.2m. Vertical confining and horizontal pullout loads were independently controlled by compressed air systems. The device has a special grip system, designed for geogrid pullout tests. Figure 2 shows details of the large shear device (Sieira et al, 2009).

Strength parameters of the silty clay were obtained from direct shear tests in the same large size device. With this procedure, scale effects were avoided when interpreting the results. Compaction conditions were also identical, with compaction degree of 95% and water content of 16 ± 0.2%. Under confining pressures ranging from 5 to 50 kPa, the strength parameters were $\phi = 21°$ and c = 30 kPa.

All laboratory tests were carried out with a woven geogrid, herein named MG, inserted in silty clay soil. According to the manufacturer, geogrid MG is bi-axially oriented, with woven fibers of high-tenacity polyester and low propensity to creep. Nominal values for longitudinal and transversal tensile strengths are 97.0 and 29.4 kN/m, respectively.



a) Construction of the field set-up *b) Cross section*

Figure 1. Experimental fill for pullot tests of geogrids (Becker, 2006).

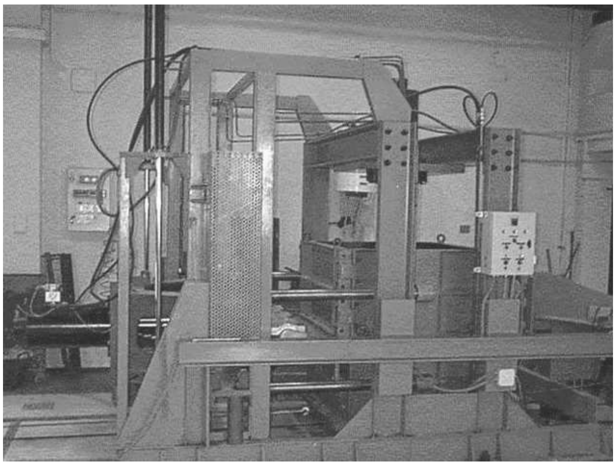


Figure 2. Large dimensions device for laboratory pullout tests.

5 FIELD AND LABORATORY RESULTS

Figure 3 presents the displacement distribution along the geogrid length, for maximum pullout load in field tests. It may be noted that increasing vertical stress leads to a smaller mobilized length. This has been also reported by Farrag et al (1993) and Lopes and Ladeira (1996). Strains were found to decrease along the specimen's length, due to the geogrid's flexibility. Consequently, the mobilized shear strength is non-uniform, being zero at the final portion.

In this paper, the mobilized length was defined as the geogrid's section with displacements larger than 1mm at the maximum pullout load. The equivalent average shear stress at the soil-geogrid interface may be defined by (Bonczkiewicz et al, 1988 e Ochiai et al, 1996):

$$\tau_{mob} = \frac{T_{\max}}{2.L_{mob}} \tag{1}$$

where: τ_{mob} is the equivalent average mobilized shear strength, T_{max} is the maximum pullout load per unit width, and L_{mob} is the mobilized length.

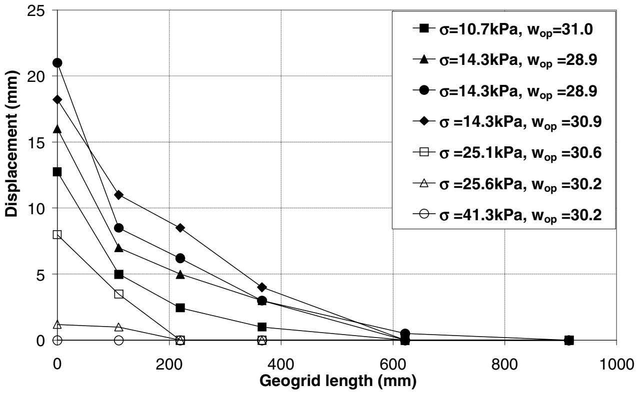


Figure 3. Distribution of displacements at maximum pullout load.

The passive resistance against transverse ribs is not explicitly considered in Equation 1. Comparison between predicted and measured pullout resistances is therefore done in terms of equivalent shear stress.

Figure 4 presents τ_{mob} as a function of the vertical stress σ_v, for tests with similar water contents and compaction degrees. A tendency for increasing τ_{mob} may be noted when σ_v increases, although more data would be desired.

Becker (2006) reports on early ruptures of the geogrid, for pullout stresses lower than the nominal tensional resistance. These ruptures occurred before the total mobilization of interface strength. The possible causes for this low resistance could be mechanical damage, preparation details or localized damage at the grip system.

Figure 5 presents the pullout test results corresponding to several confining stress levels. The pullout load increases with the frontal displacement at the grip system, until failure is reached. The larger confining stresses inhibit internal displacements of the geogrid, leading to high tensional loads at the point where pullout traction is imposed. It may be noted that, for σ_v = 50kPa, the geogrid fails by unconfined tension, not reaching the full pullout resistance.

From the laboratory test results (Fig. 5), a linear strength envelope may be obtained (Fig. 6). The test with σ_v = 50 kPa was the only one that does not fit into the linear envelope, due to unconfined tensional failure of the grid. The lab envelope was different from what was observed at field tests (Fig. 4).

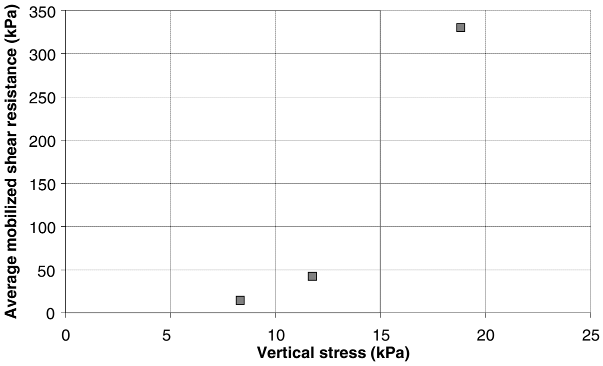


Figure 4. Mobilized shear resistance *vs*. vertical stress in the field.

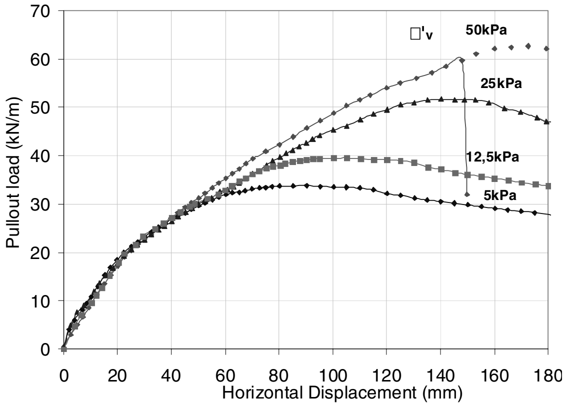


Figure 5. Laboratory pullout load *vs* frontal displacement.

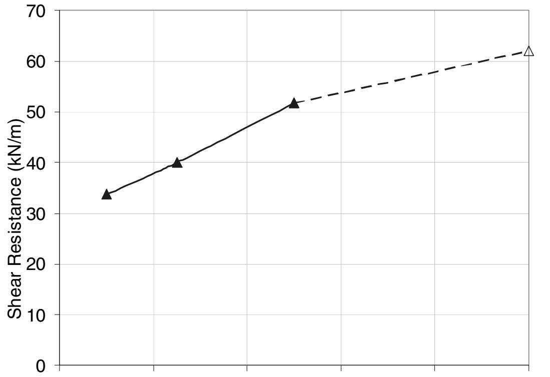


Figure 6. Strength envelope from laboratory pullout tests.

Figure 7 presents the internal displacements measured along the grid's length, for the specimen under σ_v = 25kPa, considering the mobilized resistance at 60 to 100% of maximum pullout load. For loads lower than 70% of the maximum, the geogrid experienced very low displacements within the final half of its length. Significant displacement takes place only for loads higher than 90% of the maximum pullout value.

A progressive mobilization of the displacements along the grid's length is shown to happen when the pullout load is being increased. In agreement with pullout field results, tensional strains are shown to decrease along the grid specimen. This corresponds to a non-uniformity of the soil's mobilized shear strength.

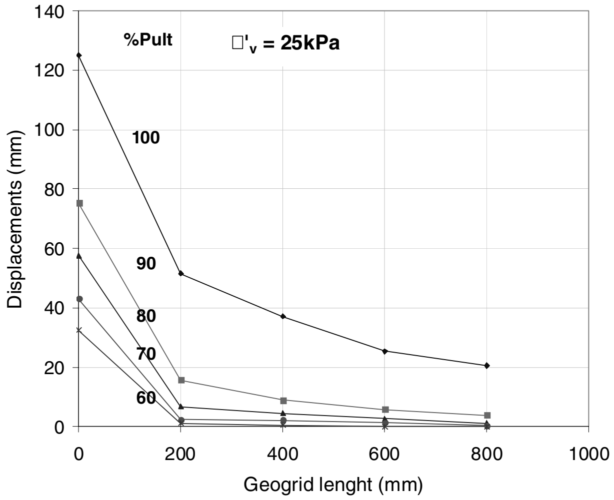


Figure 7. Geogrid's displacements for mobilized pullout levels.

6 CONCLUSIONS

This paper reports on results obtained from a large scale pullout tests of geogrids in silty clay, carried out in the field and in the laboratory. In these tests, displacement transducers were positioned along the grid specimen. The results show that, due to the grid's extensibility, decreasing displacements were observed to happen along the geogrid's length. Consequently, strains also decrease along the grid, causing the mobilized shear strain to be non-uniform, decreasing to zero at the end of the grid.

In the laboratory, an approximately linear strength envelope was observed. Only the grid tested under a relatively large confining level (50kPa) failed by unconfined tension. In the field, early ruptures were observed, corresponding to values inferior than the tensional resistance. These lower resistances were probably due to the effects of mechanical damage, grip system or set-up details.

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