Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Field and laboratory pullout tests on geogrids

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ABSTRACT: A detailed research project for studying the use of geogrids in reinforced earthfills was carried out. The soil-geogrid interaction mechanism was studied in a series of full-scale pullout tensile tests with different configurations. To carry out these tests, a reaction structure was designed and constructed for supporting a maximum tensile load of 500kN. The horizontal displacements of the geogrid were monitored with horizontal wire cables at three different locations. Geogrid specimens were placed on a compacted soil base. The surcharge was then built with compacted soil to the desired height, which was up to 2.0m. This paper aims to present details of the research, with emphasis on the pullout tests methodology and results. Differences in the load-displacement behavior of three types of geogrids in the field and the lab are discussed. The paper shows that the use of geogrids is an attractive alternative for soil stabilization projects.

1 INTRODUCTION

The technique of soil reinforcement by inclusion of geogrids has been experiencing increasing acceptance in the last few years, because it is easy to construct in the field, it is environmentally adequate and economically competitive. Geogrids are made by inter-connected elements, which are resistant to tensional loads. Their polymeric structure has openings, which are larger than the individual elements. This allows a favorable interaction with the soil matrix, causing a load redistribution at the interface. The favorable stress transfer is controlled by two basic factors: the tensional resistance of the geogrid elements and the pullout strength of the geogrid from within the confining soil.

The load transfer mechanisms in a soil reinforcement system with synthetic grids are not well known. Soils usually show a low resistance to tensional stresses. However, when the soil mass is reinforced, the lateral movement is restricted by the reinforcement's low deformability. The tendency for relative movements between soil and reinforcement grid causes shear stresses at the interface (Wheeler, 1996).

The pullout tests allows for a convenient evaluation of the behaviour of geosynthetic grids when confined within a soil mass. The pullout device should make possible the study of the effect of the several variables imposed by the testing system and different failure mechanisms. Jewel (1980) suggests using lubricated membranes on the device's lateral walls, for minimizing boundary frictional errors. Another important aspect is the interaction between the reinforced soil and the frontal wall. Williams & Houlihan (1987) used a flexible frontal wall. Palmeira & Milligan (1989) used a frontal wall with different roughness degrees.

According to Rowe & Ho (1986), the geogrid strength varies with the strain rate. Lopes & Ladeira (1996) indicate that the geogrids pullout resistance increases and anchoring length tends to be reduced with increasing strain rates.

The effect of soil thickness on the pullout resistance in clays has been studied by Brand & Duffy (1987). When soil thickness increases, the resistance decreases until reaching a minimum value. Farrag et al (1993) suggested performing load-controlled tests for investigating material behavior under long term loading conditions.

Other important factor affecting the behavior of reinforced soil is the compaction procedure (Farrag et al, 1993; Lopes & Moutinho 1997). Monitoring geogrid displacements at several locations in the soil mass is also relevant for studying the stress-strain behavior. A simple monitoring procedure using non-extensible wires has been presented by Koerner (1994).

A detailed pullout-testing program on geogrids has been carried out in the field and the laboratory, trying to incorporate all suggestions from the researchers mentioned above.

2 EXPERIMENTAL PROGRAM

2.1 *Field*

The field-testing program was carried out in a research site in Jacarepaguá, west side of Rio de Janeiro. A metallic structure has been designed and developed for field pullout tests (Medeiros et al., 1997; Sayao et al, 1999). The structure is anchored at a depth of 7m in young residual soil. The 2 anchors have been designed for pullout loads of 500kN (Figures 1 & 2).

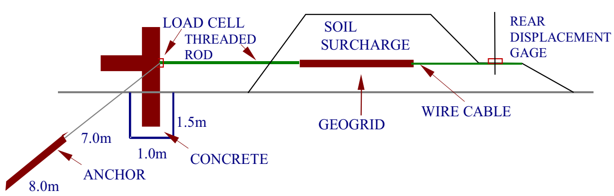


Figure 1. Schematic cross section of field pullout device.

The horizontal load was applied to 1.80m square specimens of geogrid through a system of metallic beams and grab, which compressed the specimen over its full width. This system imposed uniform frontal displacements to the geogrid.

In all tests, the geogrid specimen was placed on a 0.5m thick horizontal base layer. The loading system and the geogrid were both positioned at exactly the same level.

Confinement was provided by a 0.5m to 2.0m high fill built over the geogrid. Both the base layer and the confining fill were manually compacted, with close control of soil density.

Geogrid displacements were monitored at four distinct positions, including the frontal displacement at the pullout grab. All measurements were made to 0.5mm accuracy. Pullout loads were controlled with a 500kN capacity load cell. Acquisition of all readings was carried out with a battery operated portable device. Figure 3 shows the geogrid positioning for a field test.

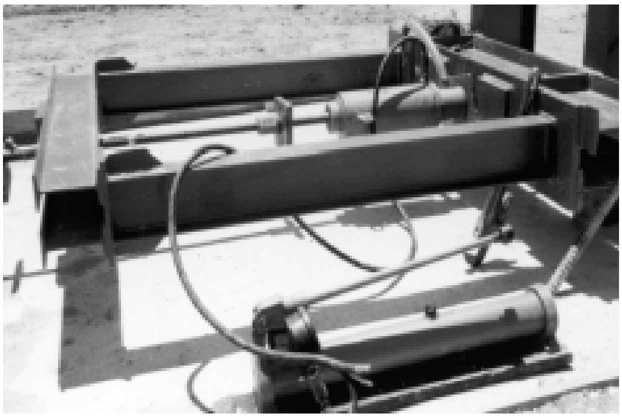


Figure 2. Detail of field pullout frame.

Figure 3. Field pullout test: positioning the geogrid on soil base.

2.2 *Laboratory Tests*

Laboratory pullout tests were performed at the CEDEX (Centro de Experimentación de Obras Públicas), in Madrid, Spain (Sieira et al, 2002). The device (Figure 4) consists of a large size cubical shear box, horizontal and vertical hydraulic loading systems and a special grab. The device is capable of testing 1.0m square geosynthetic specimens, embedded in soil. Frontal horizontal displacements to a maximum of 300mm could be imposed to the geogrid in the pullout tests.

A special grabbing system was developed for the pullout-testing program (Sieira & Sayao, 2001). Geogrid embracement by the grab became more rigid with increasing pullout load. Moreover, the grab was also designed to ensure a uniform distribution of the tensional load over the geogrids full width.

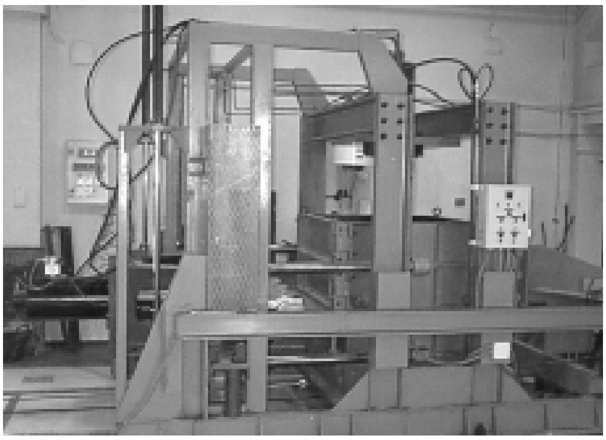


Figure 4. Laboratory pullout device.

3 MATERIALS

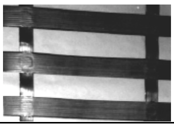
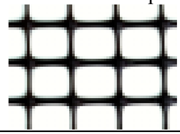
3.1 *Geogrids*

Two types of geogrids were used in the experimental program. The geogrids present different characteristics, such as structural pattern and type of polymer, as shown in Table 1.

The mono-directional geogrid (ParaGrid 200/15) presents a regular grid with inter-connected elements. These elements are made of polyester fibers, covered with a homogeneous layer of polyethylene. This geogrid exhibits a low susceptibility to creep deformations and a high longitudinal strength. A large area of contact with surrounding soil results from the wide dimensions of the geogrid elements. This is a positive characteristic, because the mechanism of frictional resistance becomes predominant, specially in applications of reinforced granular fills.

The bi-directional geogrid (LBO 440 Samp) is made of polypropylene and is manufactured by an extrusion process. This geogrid is highly stiff and strong under tensional loads and exhibits a low susceptibility to aging and installation damage. Its geometrical pattern increases interlocking with soil particles, and the interaction with transverse anchoring elements of the grid.

Table 1. Geogrids characteristics

Description	Paragrid 200/15 	LBO 440 Samp 
Manufacturer	Terram	Tenax
Structure	Mono-directional	Bi- directional
Color	Black	Black
Polymer	Polyester w/ Polyethylene	Polypropylene
Process	Thermo-welded	Extruded
Longitudinal Opening	225 mm	34 mm
Transversal Opening	75 mm	27 mm
Width	3,9m	4,0m
Tensional Resistance: Longitudinal Transversal	 200 kN/m 15 kN/m	 40 kN/m 40 kN/m
Longitudinal Strain at Failure	12%	11%

3.2 *Soils*

Two types of soils were used in the experimental program: a uniform medium sand with quartz particles and a sandy silt residual soil originated from gneissic rock.

Results of characterization tests are presented in Table 2. Strength parameters were obtained from direct shear tests with 30cm x 30cm specimens. These were reconstituted in the laboratory by manual compaction to corresponding conditions of density and water content in the field pullout tests.

Table 2. Soil characteristics

Soil	G_s (kN/m^3)	LL (%)	LP (%)	γ (kN/m^3)	ϕ' (°)	c' (kPa)
Uniform Sand	28,0	--	--	18,0	31	0
Residual Soil	27,3	45,8	27,2	17,0	34	12

4 DISCUSSION OF RESULTS

4.1 *Field Tests*

Results of field pullout tests on geogrids are presented in Figures 5 to 7. Distinct responses may be noted for the two geogrids, with significant dependence on the confining stress level, soil type and grid pattern.

The two geogrids show pullout stiffness and strength increasing with confining stress level. Load-displacement curves for the mono-directional geogrid show a non-brittle response, with a continuous increase of pullout load until failure is reached at large displacements for both soils. However, failure in tests with residual soil (Figure 6) corresponds to frontal pullout displacements of about 80mm, which are smaller than values of 100 to 120mm observed with sand (Figure 5).

Figure 7 presents load-displacement results for field pullout of bi-directional geogrid in sand. It may be noted that the pullout strength is highly affected by confining stress level. Initial stiffness, however, is nearly constant, due to interlocking of soil particles and individual elements of this bi-directional geogrid. Moreover, for tests with higher values of confining stress, a sudden tensional failure of one longitudinal element was usually observed, followed by stress redistribution and general failure of the geogrid specimen over its entire width.

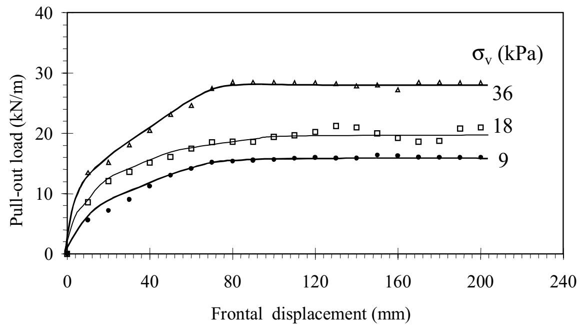


Figure 5. Field pullout tests on mono- directional geogrid in sand.

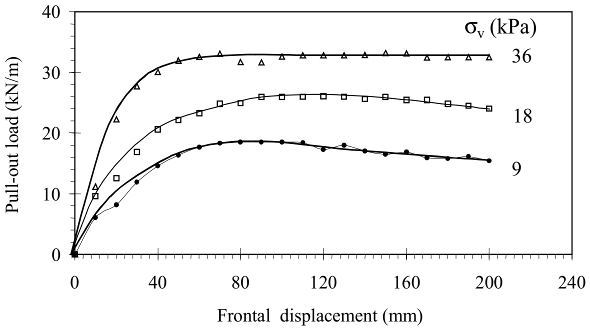


Figure 6. Field pullout tests on mono-directional geogrid in residual soil.

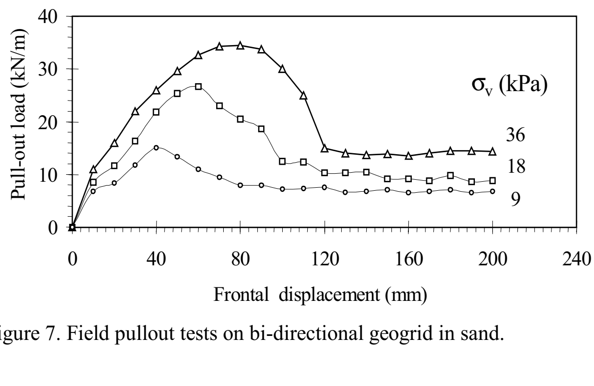


Figure 7. Field pullout tests on bi-directional geogrid in sand.

4.2 *Laboratory Tests*

Laboratory pullout results with mono-directional geogrid in sand and residual soil are shown in Figures 8 and 9, respectively.

No significant distinction may be noted for the grids pullout responses with both soils in the laboratory tests. Stiffness and strength both increase with confining stress and the load-displacement curves do not show a marked peak.

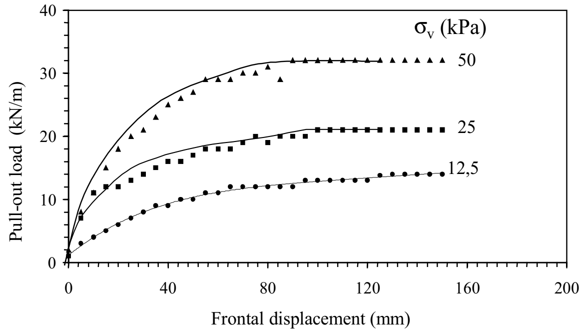


Figure 8. Laboratory pullout tests on mono-directional geogrid in sand.

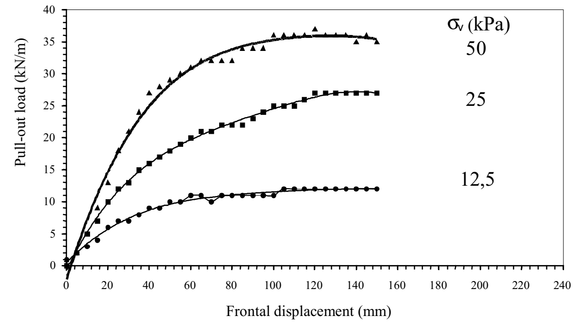


Figure 9. Laboratory pullout tests on mono-directional geogrid in residual soil.

4.3 *Comparison between Laboratory and Field Test Results*

As pullout tests were carried out on geogrid specimens with different dimensions in the field (1.8x1.8m) and in the laboratory (1.0x1.0m), direct comparison of load-displacement curves is not adequate. Instead, pullout behavior shall be compared in terms of average shear stresses acting on the soil-geogrid interface.

Shear stress was then defined as the ratio between pullout load and total interface area. With this definition, it is implicitly assumed that pullout strength is uniformly acting over the entire interface area.

Figure 10 presents a comparison between field and laboratory results for the mono-directional geogrid at two distinct confining stress (σ_v) levels. For this comparison, laboratory response corresponding to σ_v = 36kPa was estimated by direct interpolation from actual test results at σ_v=25 and 50kPa.

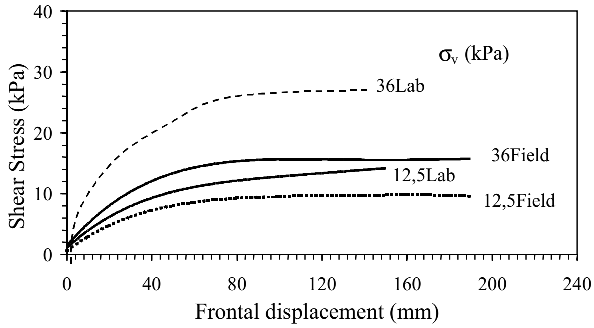


Figure 10. Field vs laboratory: mono-oriented geogrid in sand.

Similarly, field response corresponding to σ_v =12,5kPa was interpolated from test results at σ_v=9 and 18kPa. It may be noted that field strength is always lower than the lab strength. The difference may be due to friction and stress non-homogeneities at the boundaries in the laboratory device.

Figures 11 and 12 present field and laboratory pullout strength envelopes, corresponding to the two geogrids and two soil types reported in this testing program. Direct comparisons are therefore possible, aiming at assessing the influence of relevant factors on the pullout response.

It is apparent that pullout strength increases with increasing confining stress for both geogrids in both soils. It may also be noted that all failure envelopes are initially linear. This suggests that until a threshold confining stress level is reached, failure occurs by pullout mechanism only. After this threshold value, failure envelopes are governed by tensional strength of the geogrids and the envelopes become non-linear. Accordingly, failure of polymeric geogrid elements may be noted at large confining stresses.

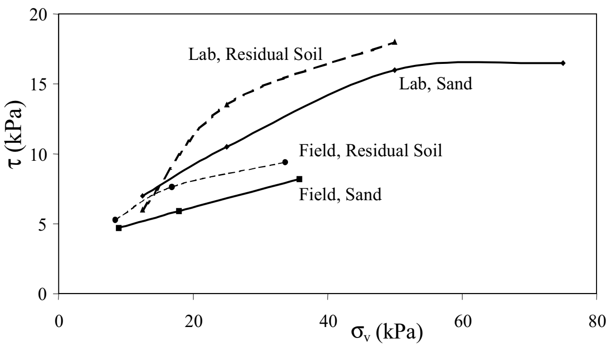


Figure 11. Pullout strength envelopes for mono-directional geogrid.

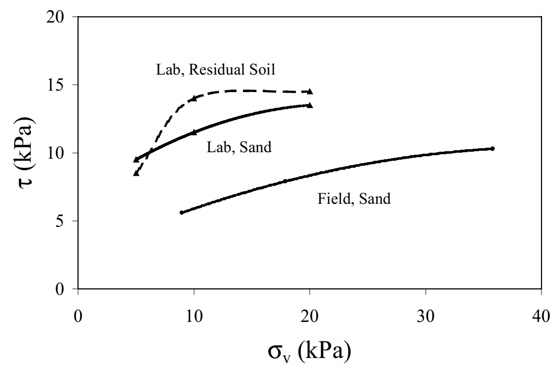


Figure 12. Pullout strength envelopes for bi-directional geogrid.

5 CONCLUSIONS

A comprehensive program of field and laboratory pullout tests on geogrids has been carried out. Two types of geogrids were considered: mono-directional polyester grid, covered with polyethylene, and a bi-directional polypropylene grid. These geogrids were confined by two types of compacted soils: medium quartz sand and gneissic residual silty soil. This paper shows that the pullout behaviour of geogrids is highly dependent on the grid's structural pattern, the confining soil characteristics and the confining stress level.

Both geogrids exhibited increasingly stiff response as the confining stress was increased. The mono-directional geogrid was always stiffer and stronger than the bi-directional one, for a same confinement level, either in field or laboratory.

Pullout strength envelopes were significantly non-linear, after an initially linear segment at low confining stresses. In the laboratory tests, the mono-directional grid presented higher tensional resistance than the bi-directional one. However, regarding pullout response, the bi-directional grid developed higher interface strength.

ACKNOWLEDGMENTS

This research project has been made possible by the technical and financial support by MACCAFERRI - Brazil. The authors thank the geotechnical section of CEDEX (Madrid, Spain) for the availability of all laboratory facilities, as part of a research cooperation program with PUC-Rio. Thanks are also due to the firm SOPE (Rio de Janeiro, Brazil) for the assistance during the field-testing program. Research assistantships were also granted by the Brazilian research agencies CNPq and CAPES.

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