Geotextiles and Geomembranes 32 (2012) 104–110

Contents lists available at SciVerse ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Technical note

Deformative behaviour of different geogrids embedded in a granular soil under monotonic and cyclic pullout loads

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ARTICLE INFO

Article history:
Received 7 March 2011
Received in revised form
18 October 2011
Accepted 2 November 2011
Available online 9 December 2011

Keywords:
Pullout
Deformation
Displacement
Cyclic
Monotonic

ABSTRACT

This paper deals with the results of a wide experimental research carried out in order to study factors affecting the cyclic and post-cyclic pullout behaviour of different geogrids embedded in a compacted granular soil. In a previous paper (Moraci and Cardile, 2009) the influence of the tensile cyclic load frequency and amplitude, vertical confining stress and geogrids structure on the pullout resistance and on the interface apparent coefficient of friction was studied. In this paper, the influence of the same factors on the pullout behaviour in terms of accumulated displacements and deformations are analysed.

1. Introduction

The better behaviour of geosynthetic reinforced earth structures, due to their high flexibility and ductility (Lee et al., 2002), compared to the behaviour of the more rigid traditional structures, in seismic load conditions has been widely shown (Tatsuoka et al., 1995, 1997, 1998; Sandri, 1997; White and Holtz, 1994; Ling et al., 2001; Sankey and Segrestin, 2001). However, these evidences were not widely supported by systematic experimental and theoretical studies about the cyclic and post-cyclic interface pullout behaviour of the geosynthetics embedded in compacted granular soils.

In fact, in order to assess the limit states of geosynthetic reinforced structures (i.e. failure and serviceability) under static and seismic loading it is important the knowledge of the interface behaviour both in terms of monotonic and post-cyclic pullout resistance and in terms of monotonic, cyclic and post-cyclic deformative (or displacement) behaviour. Moreover, the knowledge of both pullout displacements under static and cyclic loading, may be useful to develop a performance based design.

The influence of monotonic and cyclic tensile loading on pullout resistance of geogrids embedded in a compacted granular soil was discussed by the authors in a recent paper in which the influence of the tensile cyclic load frequency and amplitude, the vertical confining stress and geogrids tensile stiffness and the structure was investigated (Moraci and Cardile, 2009).

In the following paper, the influence of monotonic and cyclic tensile loading on the pullout behaviour of different geogrids embedded in granular soils in terms of accumulated displacements and deformations is analysed. In particular, the influence of the tensile cyclic load frequency and amplitude, the vertical confining stress and geogrids structure was investigated.

2. Previous researches

There is limited research on soil–geosynthetic interaction under cyclic pullout conditions in literature (Fannin and Raju, 1993; Raju, 1995; Ochiai et al., 1992; Yasuda et al., 1992; Min et al., 1995; Mayer et al., 2004; Nernheim, 2005; Fakharian and Nayeri, 2010; Giang et al., 2010). In a previous paper (Moraci and Cardile, 2009), was showed that the application of cyclic tensile pullout loads produced a decrease of peak pullout resistance and of the mobilized peak interface apparent coefficient of friction in post-cyclic condition, compared to the values obtained, in the same test conditions, in constant rate displacement (CRD) pullout tests. Moreover, the test results showed that the influence of the cyclic tensile load frequency was negligible. On the contrary, it was found that the cyclic tensile load amplitude affects the pullout response. Finally,

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doi:10.1016/j.geotexmem.2011.11.001

Table 1
Influence of vertical effective confinement pressure and of applied cyclic tensile load frequency on the deformative behaviour during the cyclic phase (geogrid GGE1).

σ'_v (kPa)	f (hz)	P_i/P_R^S	A/P_R^S	P_{max}^C/P_R^S	δ_{acc} (mm)	ε_{0-1}^C (%)	ε_m^C (%)
10.00	0.05	0.22	0.33	0.56	6.07	0.86	0.51
10.00	0.10	0.22	0.31	0.53	6.13	2.63	0.48
25.00	0.05	0.28	0.28	0.57	12.26	2.85	1.17
25.00	0.10	0.28	0.23	0.51	10.15	6.28	0.84
50.00	0.05	0.28	0.28	0.56	20.79	6.37	1.93
50.00	0.10	0.28	0.28	0.56	22.74	7.42	1.85

the obtained results showed that the post-cyclic pullout resistance increases with the increase of the geogrid tensile stiffness.

3. Experimental research

The present research was carried out using the same large pullout test apparatus (1700 × 600 × 680 mm) used by the authors in previous researches (Moraci and Recalcati, 2006; Moraci and Cardile, 2009). In particular, the test results described in this paper refers to the same soil, a uniform medium sand, and to the same geogrids, two extruded mono directional HDPE geogrids (GGE1 and GGE2) and one woven PET geogrid (GGW) having a similar peak tensile resistance to the GGE2, described in details in the previous paper (Moraci and Cardile, 2009). The pullout tests procedure (CRD and MS) used were the same described in details by Moraci and Cardile (2009). In particular, the CRD pullout tests were carried out at 1 mm/min rate (in the same test conditions used in the multistage pullout tests). The multistage pullout tests (MS) were performed in different phases. In the first phase, the pullout tests (MS) were performed under CRD equal to 1 mm/min. When a fixed pullout load was achieved (P_i), a sinusoidal cyclic tensile load of fixed frequency (0.1 and 0.05 Hz) and amplitude (15%÷45% of the CRD pullout resistance, P_R^S) was applied, at load control, for a number of cycles equal to 30. After this phase, the tests were again carried out under CRD conditions at the same displacement rate used in the first stage of the test, until the pullout or tensile failure was reached.

3.1. Experimental program

In the first phase of the research 18 pullout tests were carried out at constant rate of displacement ($v = 1$ mm/min) using the same boundary conditions of the multistage pullout tests.

All the multistage pullout tests were carried out applying 30 horizontal tensile load cycles; each test was characterized by a different tensile load amplitude, varying from 15% to 45% of the static peak pullout resistance (P_R^S) obtained by the correspondent CRD test, starting from a fixed index tensile load varying from 20% to 40% of the P_R^S.

After the cyclic phase, the multistage pullout test was continued at constant rate of displacement until a total horizontal displacement of 100 mm or tensile geogrid failure was achieved.

In order to investigate the effect of the cyclic tensile load frequency f (equal to 0.05 Hz and 0.1 Hz), 6 multistage pullout tests were performed varying the applied vertical effective stress σ'_v. These tests were carried out on a geogrid GGE1 using the same maximum cyclic tensile load equal to $P_{max}^C/P_R^S = P_i/P_R^S + A/P_R^S \cong 0.55$.

In order to evaluate the influence of the applied cyclic tensile load amplitude A, 4 multistage pullout tests were carried out on a geogrid GGE2 using a frequency f equal to 0.1 Hz and varying the cyclic tensile load amplitude ($A/P_R^S = 0.17 \div 0.42$).

Finally, the effect of the geogrid structure was analysed by means of 6 multistage pullout tests carried out on two different geogrids characterized by a similar tensile stiffness, but with different structures (GGE2 extruded and GGW woven). Also in this case the tests were performed under different σ'_v (10, 25 and 50 kPa), and the applied cyclic tensile load was characterized by a frequency of 0.1 Hz and by a maximum cyclic tensile load about equal to $P_{max}^C/P_R^S \cong 0.55$.

4. Analysis of test results

In order to study the deformative behaviour during the cyclic phase of the pullout test, the following parameters were defined and analysed:

- δ_{acc}^C = accumulated displacement measured at the specimen edge attached to the clamp during the cyclic phase of the multistage pullout test (from 1 to 30 cycles);
- ε_{0-1}^C = accumulated deformation during the cyclic phase of the multistage pullout test related to the first instrumented section of the geogrid specimen (placed close to the clamp system);
- ε_m^C = average accumulated deformation (along the geogrid specimen) during the cyclic phase of the multistage pullout test;
- $\varepsilon_{x_i-x_{i+1}}$ = total local deformation (static + cyclic), evaluated at the peak of the cyclic pullout load, defined as $\varepsilon_{x_i-x_{i+1}} = (\delta_{x_i} - \delta_{x_{i+1}})/l_{x_i-x_{i+1}}$; where δ_{x_i} and $\delta_{x_{i+1}}$ are the measured displacements corresponding to the points, along the specimen, x_i and x_{i+1} at a distance equal to $l_{x_i-x_{i+1}}$.

5. Influence of cyclic tensile load frequency (CTLF)

The analysis of the multistage pullout test results in terms of the characteristic parameters of the deformative behaviour during

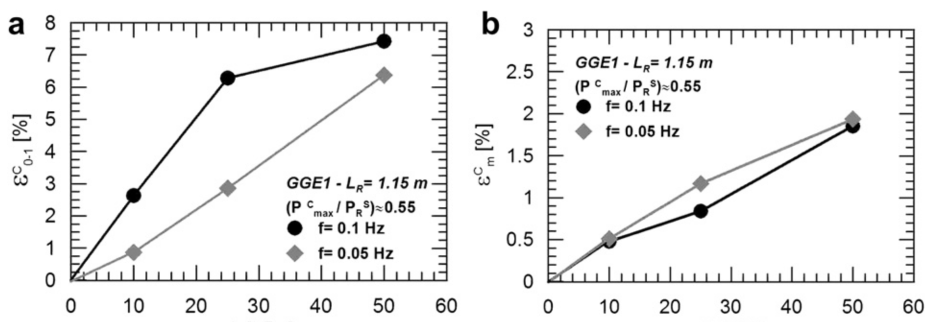

Fig. 1. Influence of the applied cyclic tensile load frequencies and σ'_v on the cyclic accumulated deformation ε_{0-1}^C (a) and on the cyclic accumulated average deformation of the specimen ε_m^C (b).