CYCLIC PULLOUT BEHAVIOUR OF EXTRUDED GEOGRIDS

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Abstract: In earth reinforced structures, geosynthetics are subject to static, cyclic and seismic loads. In order to study the interaction behaviour between soil and geosynthetics in the anchorage zone, several pullout tests have been performed in static conditions by different researchers, while few data are available in cyclic pullout conditions. Some authors have suggested that the soil-geosynthetic peak interface apparent coefficient of friction for cyclic and seismic loading should be taken as a fraction of that one for static loading, but this is not supported by large cyclic pullout experimentation.

This paper deals with an experimental research programme carried out by the geotechnical group of Reggio Calabria University, to perform many pullout tests with horizontally applied cyclic loads in granular soils by means of a large-scale pullout test apparatus (internal dimensions: 1700 mm x 600 mm x 640 mm). The vertical load application system (air bag) is static type, otherwise the horizontal force application device is an actuator to apply cyclic loads by displacement rate control or load rate control. This test apparatus has the peculiar features of a special clamp system, placed inside the soil in order to investigate the confined failure in pullout conditions. In each test condition, the friction between the clamp and the test soil has been evaluated by performing the test without the geogrid.

The tests have been performed on two HDPE extruded mono-oriented geogrids embedded in a compacted granular soil by varying the vertical effective pressures, the cyclic amplitude load and the cyclic frequency load. The analysis of the results has allowed to evaluate the cyclic pullout behaviour of the geogrid embedded in compacted granular soils and to compare the results with monotonic pullout test results carried out under the same boundary conditions.

Keywords: pull-out test, resistance, cyclic load, geogrid reinforcement, reinforced earth structure, seismic behaviour.

INTRODUCTION

Geosynthetics used in earth reinforced structures are often subjected to static loads, due to weight of structures, and to cyclical and dynamic loads due to traffic loads and earthquakes. As few studies are available in literature about the cyclic pullout behaviour of geogrids embedded in granular soils and since these studies are often disagreeing with each other, the effects of cyclic tensile loads on the pullout resistance and on the behaviour of the reinforced geogrids need more investigations. The function of the reinforcement is to improve the strength of the soil in both static and dynamic load conditions.

In the design of earth reinforced structures the reinforcement is generally characterized using standard tensile tests carried out in unconfined conditions at constant rate of displacement (EN ISO 10319) and using static pullout tests even performed at constant rate of displacement. The right design approach should take into account not only the confinement of the soil in static load conditions, but also the mechanical response under tensile cyclic loads.

The pullout behaviour of geogrids embedded in granular soils under static and cyclic tensile load conditions is studied by means of a wide laboratory investigation at the Reggio Calabria University. In this phase of the research the pullout tests are performed on HDPE geogrids previously tested in static load conditions at constant displacement rate (v=1mm/min) (Moraci and Recalcati, 2006). The cyclic behaviour has been investigated by means of multistage pullout tests carried out on the same reinforcement, the same soil and the same test conditions (length and confinement stress) used in the static pullout tests.

TEST APPARATUS

The test apparatus is composed of a pullout steel box (1700x600x680 mm), a vertical load application system, a horizontal force actuator device, a special clamp, and all the required instrumentation (Figure 1). The pullout box consists of steel plates welded at the edges; the front wall, at mid height, has an opening of 45mm of width. This opening is necessary to allow the insertion of the clamping device and of the sleeves, 0.25m long, fixed to the front wall. A smaller opening (3mm wide) is provided at the back wall of the box in order to allow the connection between the systems used to measure the internal displacements of the specimen and the transducers fixed on the external wall of the box. An air filled cushion, in which the air pressure has been carefully controlled, applies the vertical load. A steel plate is used to restrain the air cushion on the upper side. An electric jack applies the pullout force, which is measured using a load cell placed between the electric jack and the clamping system (Figure 1). The apparatus is capable to produce confined failure of the geosynthetic specimen using a clamp placed inside the soil, well beyond the sleeve in order to keep the geosynthetic specimen always confined in the soil for the test duration. The friction between the soil and the side walls of the box is minimised by the use of smooth Teflon films. The equipment incorporates two sleeves near the slot at the front of the pullout box, in order to avoid front wall effects as recommended by some researchers.

The specimen displacements have been measured and recorded using inextensible steel wires or steel rods connected to at least six different points along the geogrid specimen. The wires have been connected to displacements transducers (rotary variable displacement transducers—RVDT) fixed to the external back side of the box. All the measurements have been digitally recorded on a personal computer at defined constant time intervals.

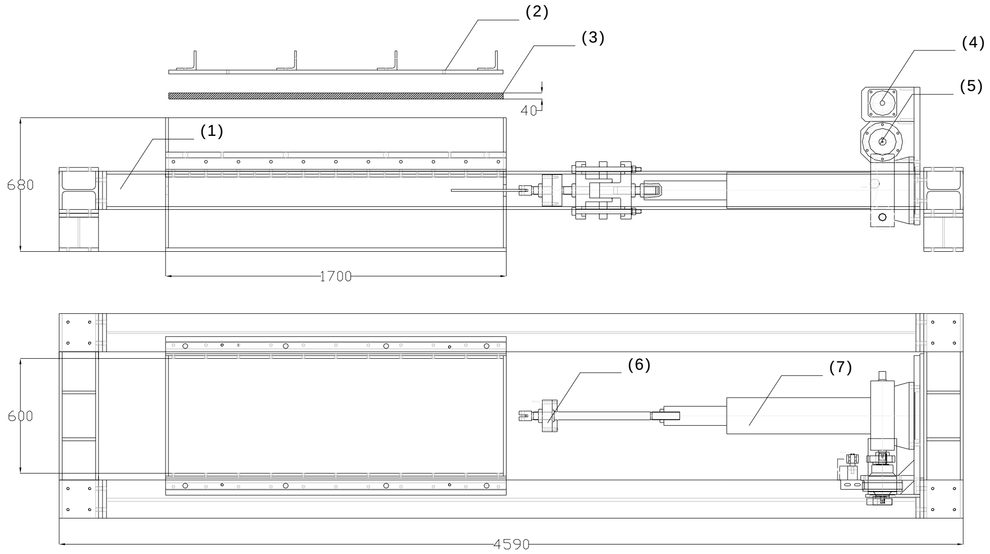

Figure 1. Scheme of pullout test apparatus: 1) frame; 2) steel plate; 3) air bag; 4) electric engine; 5) reducer; 6) load cell; 7) electric jack (Moraci and Recalcati, 2006).

TEST MATERIALS AND TEST PROCEDURE

Pullout tests have been performed on two HDPE extruded mono-oriented geogrids (described as GGE1 and GGE2); the geogrids tensile properties are reported in Table 1.

Table 1. Wide width tensile test results (according to EN ISO 10319)

Geogrid	**T_F, kN/m**	**$J_{2\%}$, kN/m**	**$J_{5\%}$, kN/m**
GGE1	90	1300	1000
GGE2	120	1800	1440

A granular soil has been used in the tests. The soil has been classified as a uniform medium sand with uniformity coefficient U=1.5 and average grain size d_{50}=0.22 mm. Standard Proctor compaction tests gave a maximum dry unit weight γ_{dmax}=16.24 kN/m^3 at an optimum water content w_{opt} =13.5%. Direct shear tests, performed at an initial unit weight equal to 95% of γ_{dmax} yielded very high single values of the peak shear strength angle ϕ'_p, in the range 48° (for σ'_v=10 kPa) to 42° (for σ'_v=100 kPa). The shear strength angle at constant volume ϕ'_{cv} was equal to 34°.

The pullout tests were performed at 95% of γ_{dmax} in order to simulate the typical construction conditions of earth reinforced structures. The pullout specimen preparation was carried out according to the test procedure described by Moraci and Recalcati (2006). In order to perform the multistage pullout test the static pullout test apparatus has been modified. In particular, the displacement measurement system has been adapted and a new software, to manage and control the different phases of test, has been developed. The multistage pullout tests were performed in different stages on specimens of length equal to 1.15 m. In the first phase, the pullout test is carried out under static load conditions (constant rate of displacement equal to 1 mm/min). When a fixed static pullout loads is achieved (P_i) a sinusoidal cyclic load of fixed frequency (0,1 and 0,05 Hz) and amplitude (15%÷45% of P_R^S) is applied for a number of cycles equal to 30.

After this phase, the test is again carried out under static load conditions, at the same displacement rate used in the first stage of the test, until the pullout or tensile failure is reached. The first and the second phase of the multistage pullout test simulate the conditions of a earth reinforced structure in which the reinforced geogrids are subjected to static pullout loads, due to the thrust of the soil, and the seismic loads produce an increment of the applied tensile loads. The last phase of the test, and the comparison of the results with the static ones, is performed in order to investigate the degradation of the pullout resistance due to cyclic loads.

ANALYSIS OF THE TEST RESULTS

The different pullout curves obtained for the geogrid GGE1 under different vertical stresses (10, 25 and 50 kPa) in static (dotted green curves) and multistage (continued red curves) pullout tests are showed in Figure 2. The multistage pullout tests refer to different tensile load frequencies, equal to 0.05 Hz and 0.10 Hz. These experimental results are comparable because the maximum applied cyclic load P^C_{max} was almost constant (about to 55% of static pullout resistance P_R^S in similar boundary conditions) in all the tests.

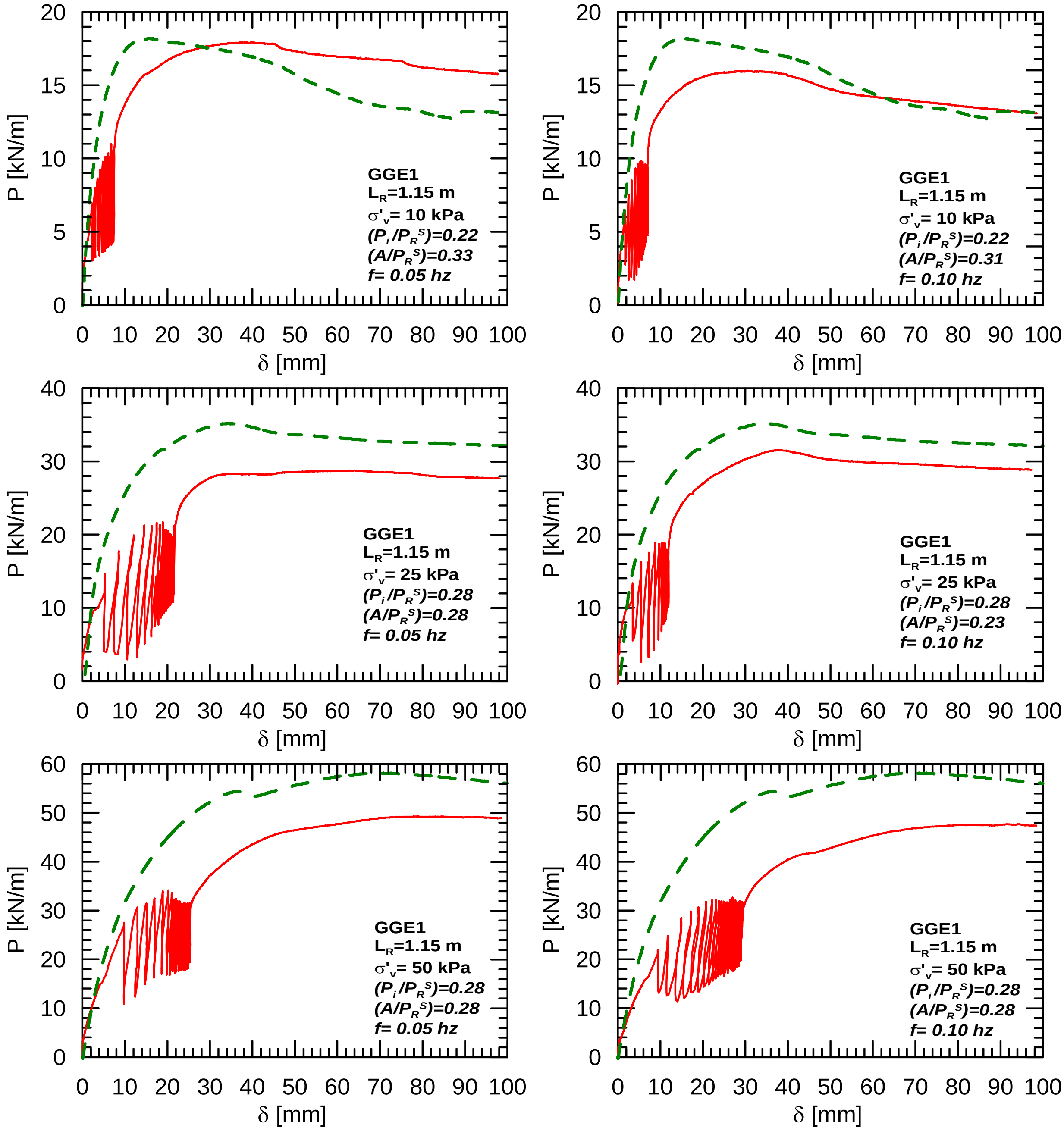

Figure 2. Comparison between static and multistage pullout tests for geogrid GGE1

From the graphs it is possible to observe that the cyclic tensile loads produced a decrease of the pullout resistance respect to the values determined in the static conditions. Moreover, it possible to notice an hardening post cyclic pullout behaviour for vertical confining stresses equal to 50 kPa; vice versa at lower confining stress (10 kPa) a softening post cyclic behaviour was observed.

The test results in terms of static and post cyclic peak pullout resistance are showed in Table 2. The comparison between static and post cyclic pullout resistances (respectively indicated with P_R^S and P_R^C) shows a decrease of the pullout resistance due to the tensile cyclic loads. In particular, the differences range from 13% to 18%, for a tensile cyclic load frequency equal to 0.05 Hz, and range from 10% to 16%, for 0.10 Hz. From these results the effects of the frequency of the applied cyclic tensile load seems to be negligible; it possible to remark only a small influence at lower vertical confining stress. Vice versa, the decrease of the post cyclic peak pullout resistance respect to static one, depends on the applied vertical confining stress, and increases with it (Table 2).

From Figure 2 it also can be possible to obtain the pullout resistance at large displacements (100 mm), both in static (P_{RR}^S) and post cyclic (P_{RR}^C) conditions. The large displacement pullout resistances measured in the pullout tests are summarized in Table 3. Also in these case it is possible to observe that the post cyclic large displacement pullout resistance was generally lower that the corresponding static one. In particular, the decrease of the pullout resistance ranges from 10% to 15%, at the higher vertical stresses (25 and 50 kPa); at lower vertical stress (10 kPa) the post cyclic large displacement pullout resistance was about equal to corresponding static value. It is possible to notice that, also in this case, the influence of the tensile cyclic load frequency is negligible. Figure 2 can be also used in order to evaluate the cumulative displacements, measured at the edge attached to the clamp, during the cyclic phase. It is possible to observe a stable behaviour characterized by cumulative displacements during the cyclic phase ranging from 4 mm to 15 mm.

Table 2. Comparison between monotonic and post cyclic peak pullout resistance for geogrid GGE1

$\sigma'_V(kPa)$	$f(hz)$	P_i/P_R^S	A/P_R^S	P_{max}^C/P_R^S	$P_R^S(kN/m)$	$P_R^C(kN/m)$	P_R^C/P_R^S
10.00	0.05	0.22	0.33	0.56	17.92	17.94	1.00
10.00	0.10	0.22	0.31	0.53	17.92	15.99	0.89
25.00	0.05	0.28	0.28	0.57	35.15	28.74	0.82
25.00	0.10	0.28	0.23	0.51	35.15	31.54	0.90
50.00	0.05	0.28	0.28	0.56	56.65	49.27	0.87
50.00	0.10	0.28	0.28	0.56	56.65	47.70	0.84

Table 3. Comparison between monotonic and post cyclic large displacement pullout resistance for geogrid GGE1

$\sigma'_V(kPa)$	$f(hz)$	P_i/P_R^S	A/P_R^S	P_{max}^C/P_R^S	$P_{RR}^S(kN/m)$	$P_{RR}^C(kN/m)$	P_{RR}^C/P_{RR}^S
10.00	0.05	0.22	0.33	0.56	13.08	15.71	1.20
10.00	0.10	0.22	0.31	0.53	13.08	13.07	1.00
25.00	0.05	0.28	0.28	0.57	32.08	27.63	0.86
25.00	0.10	0.28	0.23	0.51	32.08	28.84	0.90
50.00	0.05	0.28	0.28	0.56	56.07	48.93	0.87
50.00	0.10	0.28	0.28	0.56	56.07	47.38	0.85

The Figure 3 shows the experimental results obtained by static and multistage pullout tests carried out on the geogrid GGE2 in order to evaluate the effects of the tensile cyclic load amplitude and of the applied vertical stress on the pullout behaviour. These tests were performed for different values of vertical confinement stresses (10, 25, 50 kPa) and for a cyclic load frequency equal to 0.1 Hz, varying the tensile cyclic load amplitude from 17% to 42% of P_R^S. It is possible to observe an hardening post cyclic pullout response for vertical confining stresses equal to 50 kPa; vice versa at lower confining stress (10 kPa) a softening post cyclic behaviour was observed. The experimental results in terms of peak and of large displacement pullout resistance are summarized in Tables 4 and 5.

Also in these cases it is possible to observe a decrease of post cyclic peak pullout resistance respect to the static pullout resistance. In particular, the decrease of pullout resistance ranges from 6% to 33% (Table 4). The lower values refer to the lower vertical confining stresses, while the higher percentage values refer to the higher vertical confining stresses. Therefore, the test results show a marked influence of the tensile cyclic load amplitude at the higher vertical confining stresses (50 kPa). Vice versa, the tensile cyclic load amplitude effects were negligible at lower vertical confining stress (10 kPa). Similar conclusion can be obtained in terms of large displacement pullout resistance (Table 5). In this case, it can be observed, at lower confining stresses, a small influence of the tensile cyclic load amplitude, vice versa, for higher vertical confining stresses, the influence of the tensile cyclic load amplitude is considerable; the values of P_{RR}^C are less than the values obtained in the static pullout tests P_{RR}^S, with a percentage decrease up to 35% of P_{RR}^S. Figure 3 can be also used in order to evaluate the cumulative displacements, measured at the edge attached to the clamp, during the cyclic phase. It is possible to observe generally a stable behaviour characterized by cumulative displacements ranging from 6.5 to 12 mm. Nevertheless, is important to observe that for high confining stress and high tensile cyclic load amplitude very high cumulative displacements (larger than 50 mm) were recorded. These results show that at high vertical confining stress the increase of the cyclic tensile load amplitude could produce a degradation of the interface apparent coefficient of friction.

Table 4. Comparison between monotonic and post cyclic peak pullout resistance for geogrid GGE2

$\sigma'_V(kPa)$	$f(hz)$	P_i/P_R^S	A/P_R^S	P_{max}^C/P_R^S	$P_R^S(kN/m)$	$P_R^C(kN/m)$	P_R^C/P_R^S
10.00	0.10	0.29	0.24	0.54	20.43	17.65	0.86
10.00	0.10	0.29	0.42	0.71	20.43	19.15	0.94
50.00	0.10	0.33	0.17	0.50	60.19	49.20	0.82
50.00	0.10	0.33	0.32	0.65	60.19	40.54	0.67

Table 5. Comparison between monotonic and post cyclic large displacement pullout resistance for geogrid GGE2

$\sigma'_V\,(kPa)$	$f\,(hz)$	P_i/P_R^S	A/P_R^S	$P_{\max}^C/P_R^S$	$P_{RR}^S\,(kN/m)$	$P_{RR}^C\,(kN/m)$	P_{RR}^C/P_{RR}^S
10.00	0.10	0.29	0.24	0.54	17.43	15.58	0.89
10.00	0.10	0.29	0.42	0.71	17.43	16.24	0.93
50.00	0.10	0.33	0.17	0.50	59.39	49.14	0.83
50.00	0.10	0.33	0.32	0.65	59.39	38.77	0.65

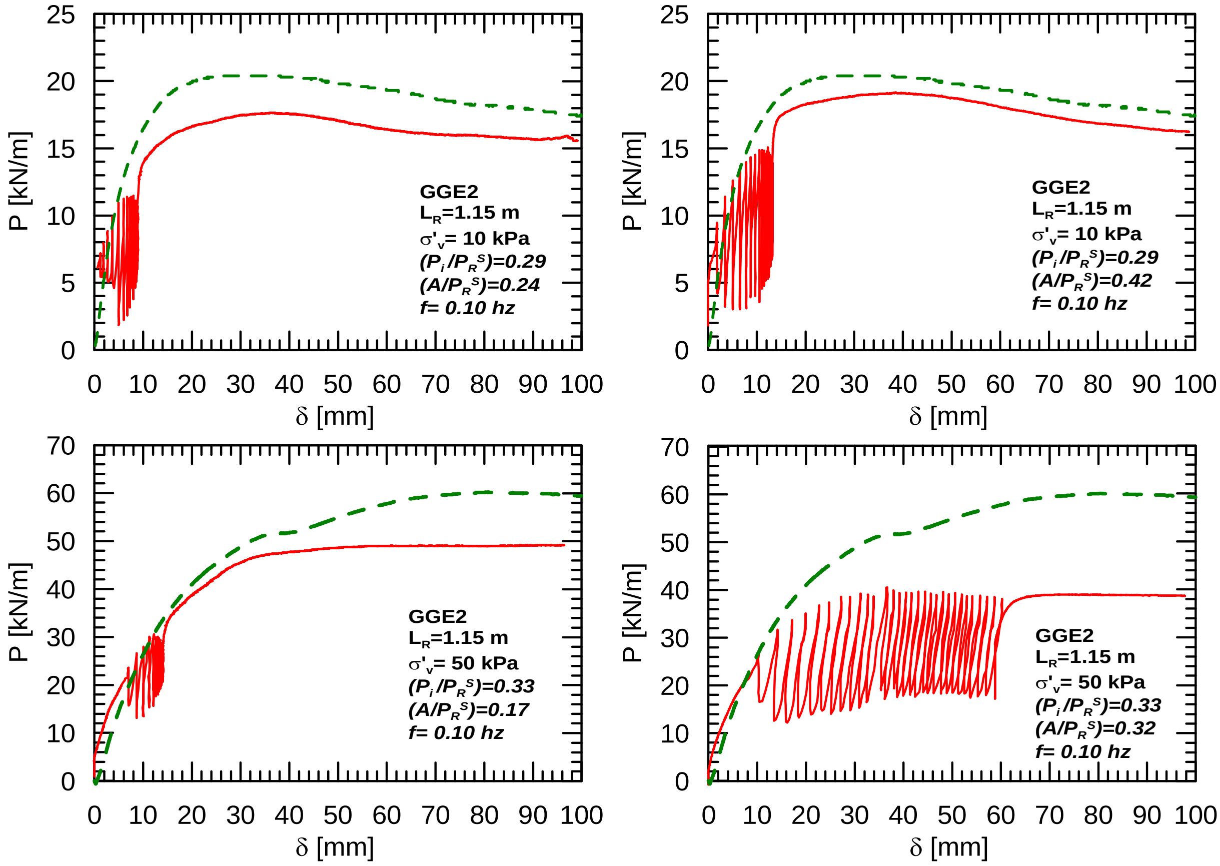

Figure 3. Comparison between static and multistage static and cyclic pullout test for geogrid GGE2

The pullout behaviour during the cyclic phase was analyzed using the conceptual model proposed by Raju and Fannin (1997). The authors, in order to analyze the stability of soil-reinforcement interface under pullout cyclic load conditions, proposed to use a double graph (Figure 4) that shows the relationship between the number of cycles N and the increment of displacements measured at the edge attached to the clamp $\Delta\delta^T$ (upper graph) and at the embedded end of the specimen $\Delta\delta^C$ (lower graph).

In the upper part of this graph a stable behaviour is characterized by a curve concave upward. In fact, a concave up curve shows that the increments of displacement decrease as the number of cycles increases. Vice versa, a convex curve denotes an unstable behaviour of the soil reinforcement interface; the increments of displacements increase with the increase of the number of cycle N.

Nevertheless, it is important to observe that also a concave up curve can be unacceptable if cumulated displacement during the cyclic phase is larger than the displacement required in order to verify the serviceability limit state. Therefore, in this study, a limit admissible cumulative displacement equal to 30 mm was defined according to Allen and Bathurst (2002). This modified approach was used for analyzed research test results. In the bottom part of the graph the dotted line represent the pullout failure condition line in which $\Delta\delta^T$ is equal to $\Delta\delta^C$, so that a stable behaviour is characterized by a curve above the dotted line.

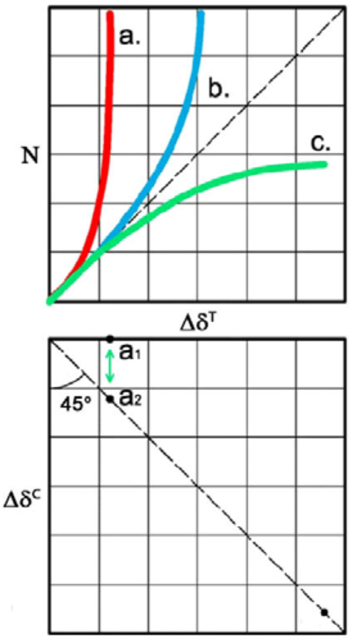

Figure 4. Stability analysis scheme according to Raju and Fannin (1997)

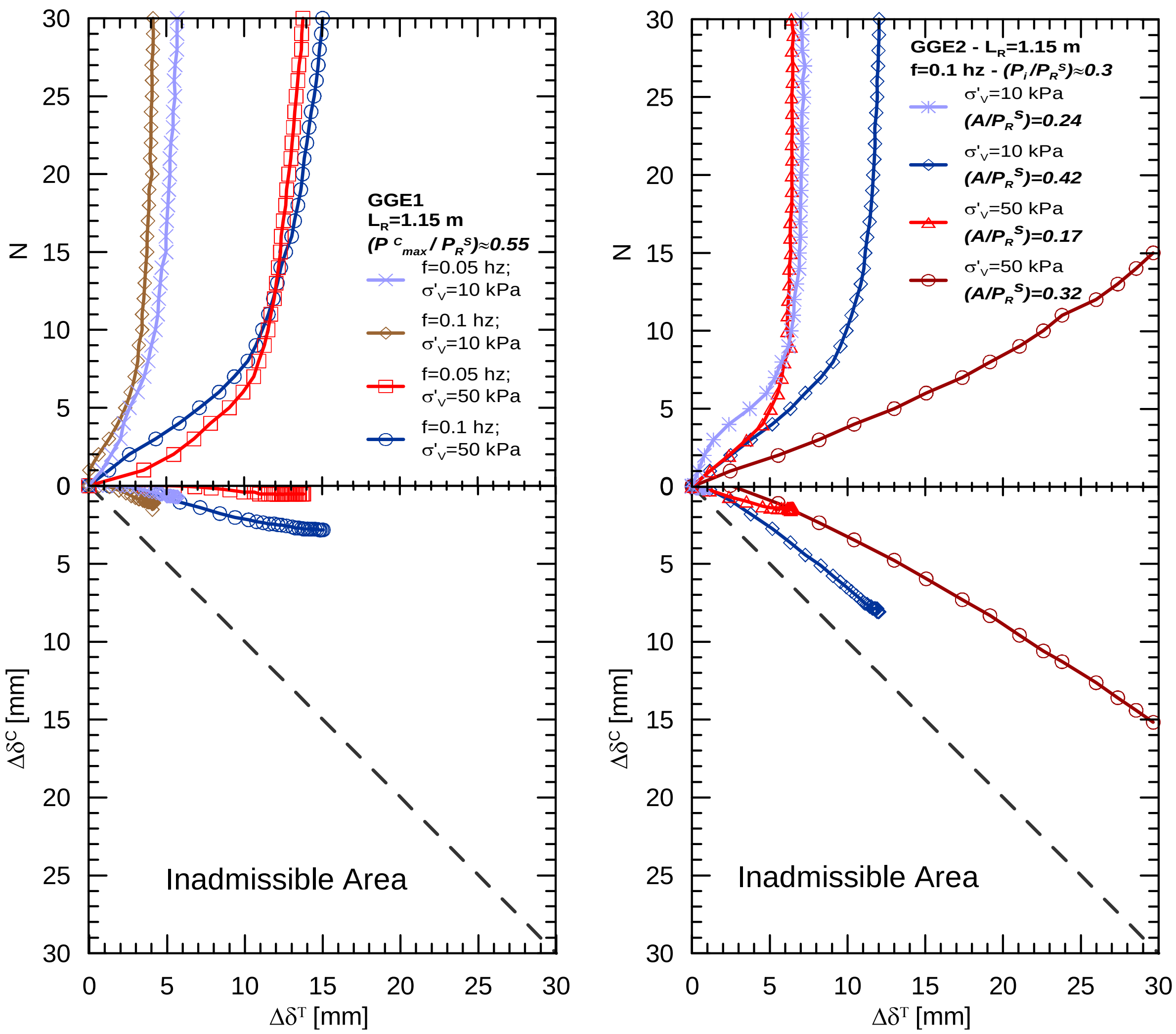

Figure 5. Analysis of pullout behaviour during the cyclic phase: a) geogrid GGE1- b) geogrid GGE2.

The graphs in Figure 5 show the experimental results of the different pullout cyclic tests according to the modified conceptual model proposed by Raju and Fannin (1997). In particular, the Figure 5a refers to the cyclic pullout tests carried out on the geogrid GGE1 in order to study the influence of tensile cyclic load frequency and of the vertical stress; while the Figure 5b refers to the cyclic pullout tests carried out on the geogrid GGE2 in order to study the influence of tensile cyclic load amplitude and of the vertical stress. It's possible to observe that the behaviour during then cyclic phase is generally stable in all the tests. Only in the test performed at 50 kPa and at high tensile cyclic load amplitude a not acceptable cumulative displacement occurs.

CONCLUSIONS

The test results clearly show the effects of tensile cyclic loads on pullout behaviour of geogrid embedded in compacted granular soil. In particular, the main conclusions are:

- The comparison between the pullout curves obtained in the static and in the multistage static and cyclic pullout tests shows a decrease of pullout resistance due to the tensile cyclic loads;
- The effects of the cyclic load frequency seems to be negligible;
- The post cyclic pullout resistance and the cumulative displacement during the cyclic phase depends on the cyclic load amplitude;
- Generally, the cyclic behaviour of geogrid has been stable: the increment of displacements decreases as the number of cycles increases.

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