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Experimental evaluation of the factors affecting pull-out test results on geogrids

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ABSTRACT: A new pull-out test apparatus has been designed, which is similar in dimensions to the ones already under discussion (that is 1.5 m x 0.6 m x 0.7 m) in different Standardization Bodies, but with peculiar features in terms of measurement of the internal displacement along the reinforcement and for a special clamp which is placed inside the soil in order to investigate the confined failure in pull-out condition. Tests have been performed on a granular soil and an HDPE extruded geogrids. The discussion of the results of this vast research program allows to evaluate the influence of test parameters on pull-out test results.

1 INTRODUCTION

The apparatus and procedure for pull-out tests on Geosynthetics are currently under discussion in several Standardization Bodies all over the world.

Pull-out tests are necessary in order to study the interaction behaviour between soil and Geosynthetics in the anchorage zone, hence these properties have direct implications in the design of reinforced soil structures.

To be really usable for design, pull-out tests shall be performed in such a way as to reproduce as close as possible the actual conditions that a geosynthetic undergoes when embedded in soil in a reinforced soil structure.

In order to provide a positive contribution to the development of a proper standard, which could be used for design purposes, a research program has been carried out for investigating the influence of the main parameters on pull-out test results on geogrids embedded in granular soils.

Therefore a new test apparatus has been designed, which is similar in dimensions to the ones already under discussion (1.5 m x 0.6 m x 0.7 m), but with peculiar features in terms of measurement of the internal displacement along the reinforcement and for a special clamp which is placed inside the soil in order to investigate the confined failure in pull-out loading condition.

More than 25 tests have been performed, varying both the width of the specimens and their length, at vertical confining pressures equal to 10, 25, 50 and 100 kPa.

The discussion of the results of this research program allows to evaluate the influence of different test parameters on pull-out test results. Therefore the results of the research can be very useful for the final development of an international test standard, which could provide performance values for the design of geogrid reinforced soil structures.

2 TEST EQUIPMENT AND PROCEDURE

The test apparatus, shown in Figure 1, is composed by a pull-out box, a vertical load application system, a horizontal force application device, a special clamp, and all the required instrumentation.

The box dimensions and the clamping device were designed on the base of the interaction mechanisms between soil and geogrid in pull-out loading conditions (Palmeira and Milligan, 1989; Farrag et al., 1993).

The height of the box (640 mm) comes from the shape of the passive failure surface, which is supposed to involved a soil thickness equal to 40 times the thickness of the geogrid bars.

The need to avoid wall effects at the front of the box suggested to use smooth steel profiles (sleeves), 200 mm long (Fig. 1), connected to the front wall.

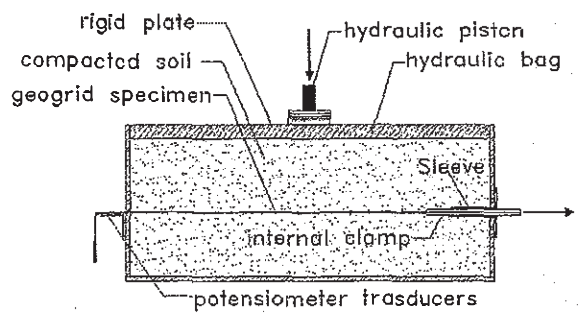

Figure 1. Scheme of the test apparatus.

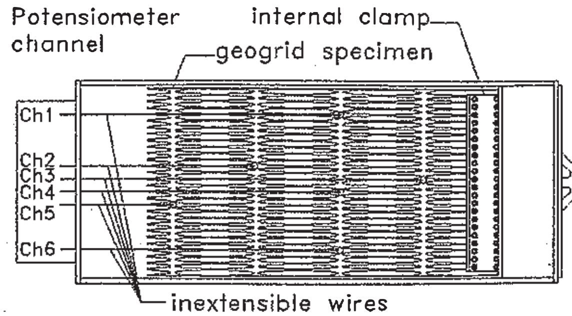

Figure 2. Schematic plan view of the test apparatus.

The width of the box (600 mm) comes from the need to include an adequate number of geogrid ribs in order to reproduce properly the behaviour of the reinforcement when embedded in the soil.

Finally the box length (1500 mm) was selected with the aim of investigating the soil – geogrid interaction for different reinforcement length, particularly at low confining pressure, when the potential of geogrid pull-out is more evident. For high confining pressures, instead, the failure mechanism becomes the tensile rupture of the geogrid.

The confined failure has been studied by using a clamp placed inside the soil, beyond the sleeve, in order to keep the geogrid specimen always confined in the soil during the whole test duration (Fig. 2).

The vertical load has been applied through a hydraulic jack, controlled by a servo-hydraulic multi axial closed loop digital controller type Instron 8580. The hydraulic jack push against a rigid steel plate, which lays on water filled cushion, used to distribute the load evenly on the soil surface.

The horizontal force has been applied through another hydraulic jack, controlled by the same Instron 8580, connected to the clamp through a chain.

During the test the following parameters have been measured and recorded (by the Instron digital controller): vertical load, vertical displacement, pull-out displacement rate, pull-out force, displacement of the transversal bars of the geogrids in at least six different points.

This last measurement has been made through inextensible steel wires, cased into rigid PVC micro tubes, connected to the geogrid bars at an end and to the electrical displacement transducers at the other end, outside the pull-out box. The transducers are connected to the Instron controller, which digitally records all the data at defined time intervals. This system allows to follow the pull-out dynamics along the whole specimen length (Fig. 3).

All tests have been performed on one type of HDPE extruded mono-oriented geogrid (Tenax TT 090 SAMP). Wide width tensile tests (EN ISO 10319) on this geogrid have been carried out at different displacement rate (1, 10, 100 mm/min); the test results are reported in Figure 4 and Table 1.

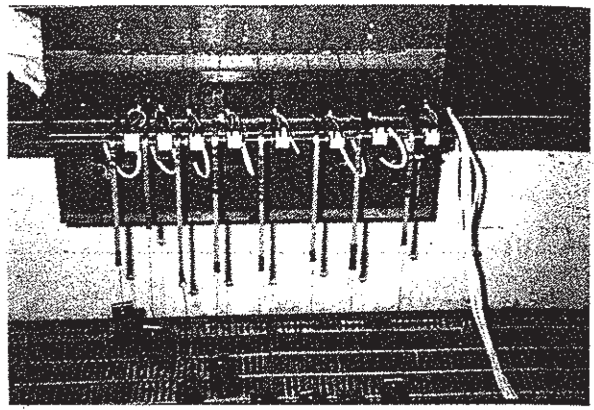

Figure 3. The electrical displacement transducers.

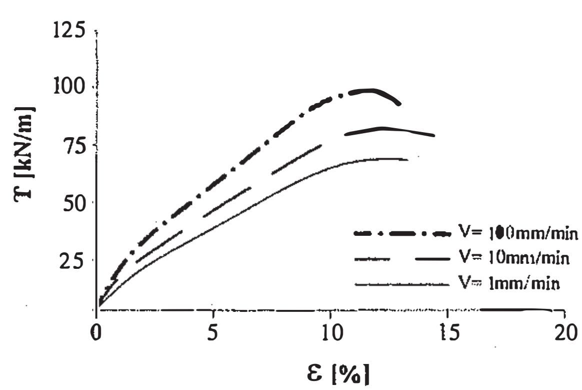

Figure 4. Tensile tests at different displacement rate.

Table 1. Results of tensile tests at different displacement rate.

V (mm/min)	T (ε=2%) (kN/m)	T (ε=5%) (kN/m)	Tmax (kN/m)
100	29.47	53.85	95.19
10	23.33	43.27	79.96
1	18.93	35.97	66.73

The soil was tested for the main geotechnical parameters: results of classification tests indicate that the soil is a medium sand (SP according to USCS system), with uniformity coefficient $Cu=D_{60}/D_{10}=1.5$ and average grain size $D_{50}=0.22$ mm.

The Standard Proctor compaction test indicates a maximum dry unit weight $\gamma_{dmax}= 16.24$ kN/m^3 at a water content $w_{opt}= 13.5\%$.

Direct shear tests, performed at an initial unit weight equal to 95% of γ_{dmax} (obtained at a water content of 9.3%), yield very high single values of the peak shear strength angle ϕ'_p, in the range between 48° and 42°, where the higher values correspond to the lower confining pressures, while the shear strength angle at constant volume ϕ'_{cv} results equal to 34°.

The pull-out test procedure was the following:

1) preparation of the surfaces of the pull-out box: in order to minimize the friction between the soil

and the box, all the box walls have been covered with adhesive Teflon film;

2) filling and compaction of the soil in the lower half of the box: the soil, previously dried in oven at 105 °C for 24h, has been prepared at a water content of 9.3%; after it was laid in the box in 100 mm thick layers and manually tamped till a final thickness of 0.265 m;
3) positioning of the clamp and connection to the geogrid specimen; the parallelism of the specimen with the box length and the perfect horizontality have been carefully checked; a small preload has been applied to the geogrid in order to avoid any waving;
4) insertion of the inextensible wires into the PVC tubes and connection to the geogrid bars and to the electrical transducers;
5) filling and compaction of the soil in the upper half of the box, for a final thickness of 0.265 m;
6) placing of the water filled cushion and the steel plate on top of soil; connection of the jacks and the instrument to the Instron controller;
7) setting of the horizontal testing speed and the vertical applied force, and starting of the test.

More than 25 tests have been performed, varying both the width and length of the specimens. The applied vertical pressures were equal to 10, 25, 50 and 100 kPa. The horizontal displacement rate has been equal to 1.0 mm/min for all tests.

All tests have been performed, until geogrid rupture or till a total horizontal displacement of 100 mm in this way the geogrid specimen remains always confined in the soil for its whole length.

The friction between the clamp and the test soil has been evaluated, for each confining stress, by performing pull-out tests on the clamp embedded in soil without the geogrid specimen. The pull-out force values obtained have been subtracted, at each displacement level, from the pull-out forces measured in the tests with the geogrids at the same displacement and at the same confining stress.

3 EXPERIMENTAL RESULTS

The results obtained in the first phase of this research are synthetically reported in Table 2.

Thanks to the clamp inserted into the soil the mechanism of pull-out failure, with the specimen constantly and wholly confined by the soil, has been properly studied. From Figure 5, representing the pull-out force versus the first bar displacement for the two tests carried out with the same specimen length, L_R= 1.15 m, but different specimen width (i.e. W = 0.40 m and 0.58 m) at a vertical pressure of 100 kPa, it can be noted that tensile rupture of the geogrid occurred at 66.55 kN/m tensile force, for W = 0.40 m, and at 62.27 kN/m for W = 0.58 m.

Table 2. Pullout test results.

Confining stress σ_v' (kPa)	Specimen lenght L_R (m)	Specimen width W (m)	Maximum Pullout Force $Tmax_{po}$ (kN/m)
10	1.15	0.40	15.80
25	1.15	0.40	32.18
50	1.15	0.40	55.08
100	1.15	0.40	Geogrid rupture
10	1.15	0.58	14.43
25	1.15	0.58	25.70
50	1.15	0.58	50.58
100	1.15	0.58	Geogrid rupture
10	0.90	0.40	12.84
25	0.90	0.40	29.06
50	0.90	0.40	43.79
100	0.90	0.40	65.60
10	0.90	0.58	9.77
25	0.90	0.58	24.83
50	0.90	0.58	37.64
100	0.90	0.58	57.22
10	0.40	0.40	4.87
25	0.40	0.40	13.59
50	0.40	0.40	22.99
100	0.40	0.40	29.52
10	0.40	0.58	4.68
25	0.40	0.58	10.93
50	0.40	0.58	15.94
100	0.40	0.58	27.69

These values are very close to the tensile strength (66.73 kN/m) obtained by the wide width tensile tests performed at the same rate (v = 1 mm/min) of the pull-out tests (Tab. 1). Being the short term tensile properties of geogrids practically unaltered by the soil confinement, at least for the type of soil and reinforcement used in this research, there is now the need to evaluate whether the long term strength, commonly used for the design of reinforced soil structure, remains unaltered as well when the geogrids are embedded in a compacted soil.

Since the confined condition produces a variable tensile stress level along the reinforcement due to the reinforcement extensibility and to the different interaction mechanisms (Moraci and Montanelli, 2000), in-soil creep tests may produce substantially different results than in-air creep test, where the ten-

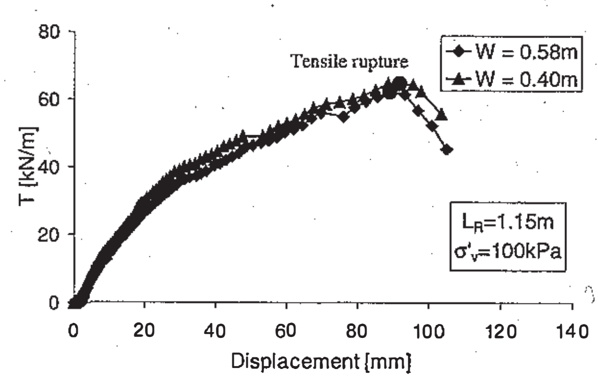

Figure 5. Tensile rupture in pull-out loading conditions.

sile stress is constant along the whole specimen. Recent studies on instrumented reinforced walls seems to confirm this fact (Carrubba et al. 2000).

The apparatus here presented seems to be suitable to run such long term in-soil pull-out tests in laboratory controlled conditions.

Analysing the pattern of the pull-out resistance versus the displacement of the first embedded geogrid bar (Fig. 6), it is evident that the interface behaviour is strongly influenced by the embedded geogrid length.

In fact, tests performed on "long" specimens (L_R = 0.90 m and L_R = 1.15 m) show a strain hardening behaviour, with a progressive increase of the pull-out resistance with the increase of the displacement of the first embedded geogrid bar; while tests on "short" specimens (L_R= 0.40 m) show a strain softening behaviour, with a progressive decrease of pull-out resistance after the peak. It is therefore possible to say that the pull-out interaction mechanism is progressively developed along the long reinforcement layer, while it is developed almost at the same time along the whole length of short layers. In this latter case the pull-out resistance shows a pattern similar to stress-strain curves of compacted soils.

Such result is confirmed by the analysis of the bar displacements along the specimen for different ap plied tensile forces. Here it is possible to observethe two different phases that characterize the pull-out of the reinforcement from the soil: first the tensile force is progressively transferred to the geogrid (Fig. 7), until the whole embedded length become under tension and also the last point of the geogrid start to be displaced; in the second phase (Fig. 8) the pull-out resistance increases until a peak (for short reinforcements) or up to maximum pull-out force or up to geogrid tensile rupture (for long specimens).

In details, there is a non-linear distribution of the displacements for long geogrid layers (L_R = 0.90 m e L_R = 1.15 m), hence a markedly non linear interface behaviour, due to the deformability of the reinforcement and to the various other factors affecting the complex interaction between soil and open grid structures (Moraci and Montanelli, 2000). With short layers (L_R= 0.40 m), after the "loading" phase (Fig. 9), displacements become practically constant along the geogrid (Fig. 10), therefore showing a similar behaviour to very stiff reinforcing elements like steel bars.

Comparing the tests with different specimen width (Fig. 11), we can note that the pull-out resistance is higher for narrow specimens, at equal vertical pressure and specimen length: the difference of pull-out resistance between the 0.40 m wide and the 0.58 m wide specimens vary from 4 % (for short length and high pressure) to 43 % (for long length and low pressure). This differences can be explained by the effects of constrained dilatancy at the geogrid

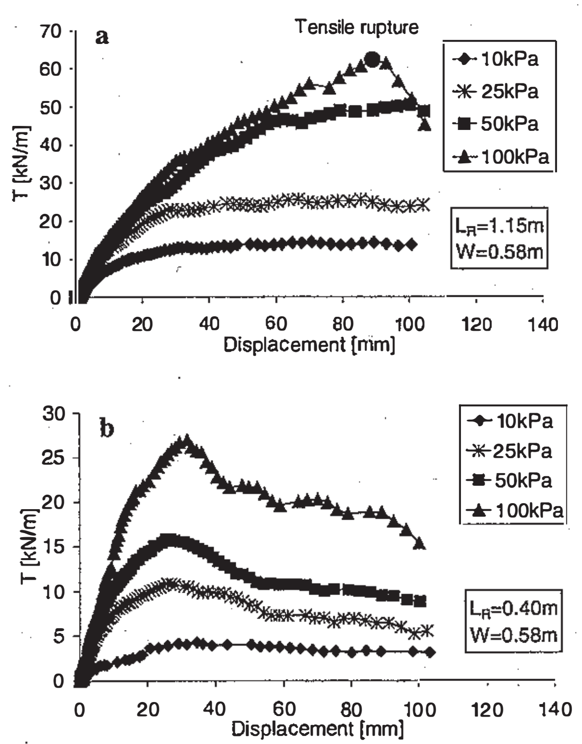

Figure 6. Pull-out curves: a) long specimen; b) short specimen.

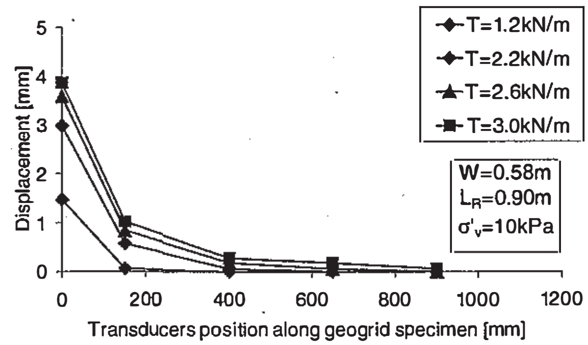

Figure 7. First phase: tensile force transfer.

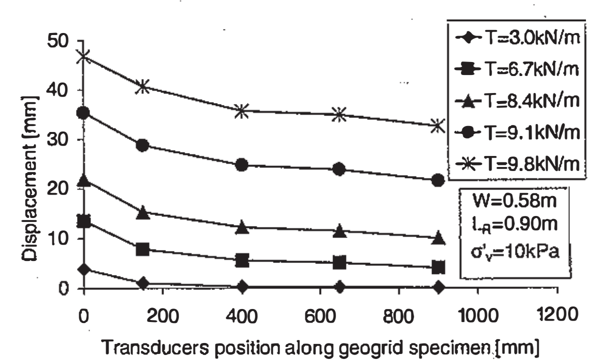

Figure 8. Second phase: pull-out.

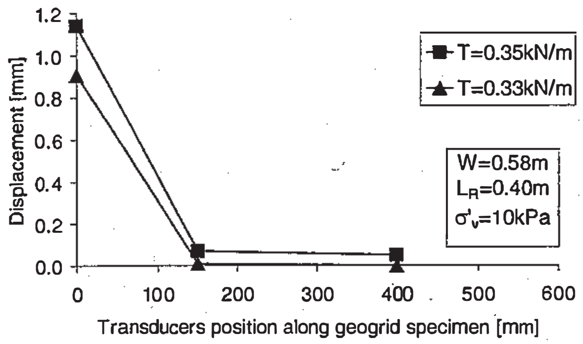

Figure 9. First phase: tensile force transfer.

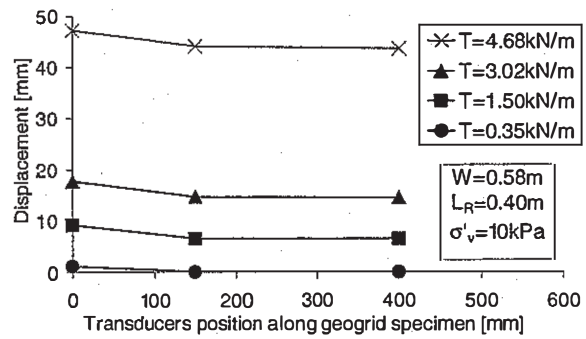

Figure 10. Second phase: pull-out.

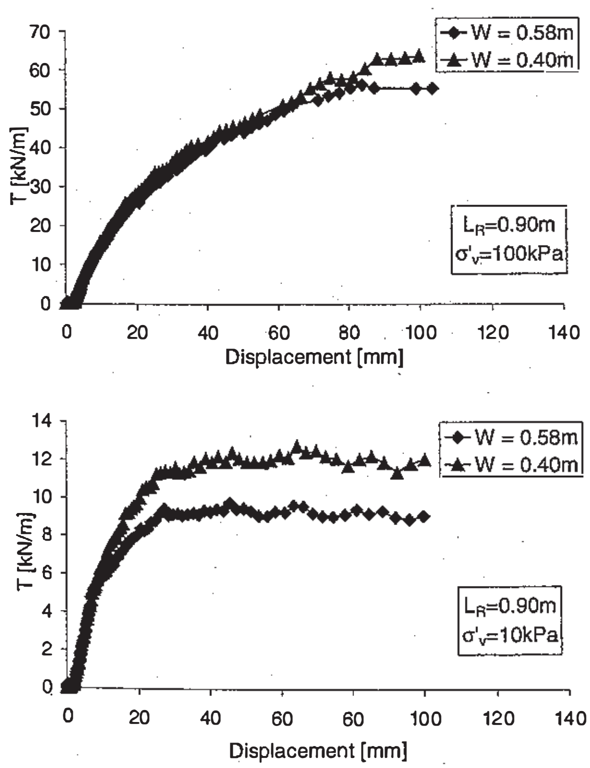

Figure 11. Pull-out curves for specimens of different width.

soil interface along the geogrid edges: such effects have large influence on specimen narrower than the box width. For 0.40 m wide specimens the tendency of the soil to dilatancy develops a three-dimensional effect (Hayashi et al.1996). In fact, the non dilating zone in the soil surrounding narrower geogrid specimens (zone a in Fig.12) behave as a restrain against soil dilatancy in the dilating zone (zone b in Fig.12). This in turn generates shear stresses at the border between the two zones and produces an increase of the effective normal stress on the soil – geogrid interface and, consequently, an increase of pull-out resistance. By increasing the specimen width such effect is reduced because the soil area that block the dilatancy decreases, and the shear stresses cannot be generated anymore, thanks to the smoothness of the box walls lined with Teflon film (Fig. 12).

The pull-out factor f_{po} can be calculated directly from the tests results: it depends clearly on anchorage length and width, on the vertical pressure, and on the value assumed for the shear strength angle of the soil. In Figure 13 the experimental results are compared with values obtained by Jewell (1984 ,1985) and Matsui (1996), through theoretical approaches: it can be noted that the theoretical approaches tend to underestimate f_{po}. In particular, with the use of the constant volume shear strength angle, suggested by Jewell, (1984, 1985), the theoretical expressions yield constant values of f_{po}, independent of the geogrid length and the vertical pressure, which is in contrast with experimental evidence. This is probably due to the fact that the theoretical expressions proposed so far don't take into considerations all the factors influencing the pull-out phenomenon. A correct way of evaluating f_{po} would be to use values of the soil shear strength angle related to the reinforcement behaviour and to the applied vertical effective stress. Considering the two different modes of pull-out resistance mobilization, it seems more appropriate to evaluate the pull-out factor f_{po} using values of the shear strength angle close to the peak one (evaluated for the applied vertical effective stress), for short reinforcement layers, and intermediate values between the constant volume and the peak shear strength angle for long geogrid layers.

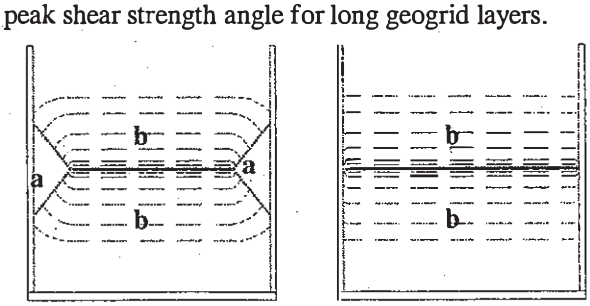

Figure 12. Scheme of the interaction for narrow and wide specimens.

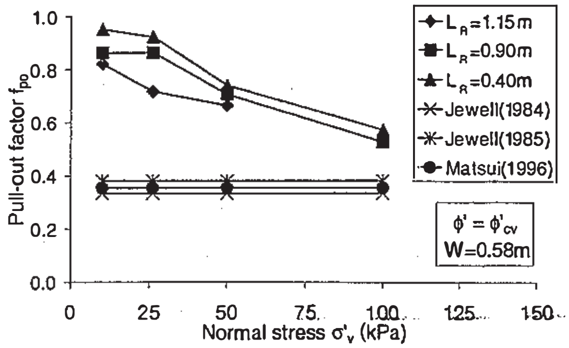

Figure 13. Pull-out factor vs.σ'$_v$ at different specimen lenghts.

Finally it must be noted that tests performed with the specimen width narrower than the box width yields values of f_{po} that are higher (hence less conservative) than the ones obtained with specimens covering the full box width.

4 CONCLUSIONS

The main conclusions of the present work are the following:

1 In the experimental conditions the influence of soil confinement on the short term tensile strength of geogrids is negligible;
2 The interface behaviour is strongly influenced by the embedded geogrid length: tests performed on "long" specimens show a strain hardening behaviour, while tests on "short" specimens show a strain softening behaviour;
3 For the design of reinforced soil structures, where generally the geogrids cover the whole horizontal area, pull-out tests shall be performed with specimen width equal to the box width, in order to avoid three-dimensional effects that cannot occur in reality;
4 Theoretical expressions (Jewell, 1984, 1985; Matsui et al. 1996) tends to underestimate the pull-out factor f_{po}; a proper evaluation of f_{po}, shall be made on the base of pull-out test results using the appropriate value of the soil shear strength angle.

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