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Pullout behaviour of geogrid embedded in granular soils

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ABSTRACT: The paper deals with preliminary results of a large experimental program aimed to study the behaviour of geosynthetics embedded in compacted granular soils in short and long-term pullout conditions. In this paper the results of pullout tests performed at constant displacement rate on HDPE extruded geogrid embedded in two different compacted granular soils are analysed. The discussion of the results of this phase of the research program allows to evaluate the influence of reinforcement length, confining stress and soil type on interface behaviour in pullout condition. In particular, the influence of the mobilization of interface shear strength and the dilatancy effects on soil-geogrid pullout interaction are discussed.

1 INTRODUCTION

Pullout 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, pullout 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 previous papers the large scale test apparatus designed in order to carry out the research and the influence of different test parameters on pullout test results has been described (Moraci & Montanelli 2000, Ghionna et al. 2001). The discussion of the previous results was useful for the final development of the proper test procedure. In particular, for the design of reinforced soil structures, where generally the geogrids cover the whole horizontal area, pullout tests shall be performed with specimen width equal to the box width, in order to avoid three-dimensional effects (Hayashi et al. 1996) that cannot occur in reality. Moreover, it was found that the influence of soil confinement on the short term tensile strength of geogrids is negligible (Moraci et al. 2001, Ghionna et al. 2001) at least for the type of soil and reinforcement used, there is the need to evaluate whether the long term tensile 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 confinement in soil produces, in pullout condition, a variable tensile stress level along the reinforcement, due to the reinforcement extensibility and to the different interaction mechanisms (Moraci & Montanelli 2000), in-soil pullout creep tests may produce substantially different results than in-air creep test, where the tensile stress is constant along the whole specimen. Recent studies on instrumented reinforced walls seem to confirm this fact (Carrubba et al. 2000).

In order to study the interface behaviour also in long-term pullout loading conditions, a large scale apparatus has been designed; it is presently under construction and it will be used for the next phases of the research program.

In this paper the short term pullout tests performed at constant displacement rate on HDPE extruded geogrid embedded in two different compacted granular soils are analysed. The discussion of the results allows to evaluate the influence of reinforcement length, confining stress and soil type on interface behaviour in pullout condition. In particular, the influence of the mobilization of interface shear strength and the dilatancy effects on pullout soil-geogrids interaction are discussed.

2 TEST EQUIPMENT, MATERIALS AND RESULTS

The test apparatus is composed by a pullout box (1500 x 600 x 640 mm), a vertical load application system, a horizontal force application device, a special clamp, and all the required instrumentation (Moraci & Montanelli 2000, Ghionna et al. 2001).

The apparatus is capable to produce the confined failure of geosynthetic specimen by using a clamp placed inside the soil, beyond the sleeve, able to keep the geosynthetic specimen always confined in the soil for the whole test duration.

The displacements of the specimen have been measured and recorded through inextensible steel wires connected to the specimen, in at least six different points, and to RVDTs fixed to the external back side of the box.

All the pullout 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); and in particular at the same speed (1 mm/min) of the pullout tests; the tensile test results are reported in Table 1.

Table 1. Wide width tensile tests result at different displacement rate.

Displ. rate (mm/min)	$T_{2\%}$ (kN/m)	$T_{5\%}$ (kN/m)	T_F (kN/m)
100	29.47	53.85	95.19
10	23.33	43.27	79.96
1	18.93	35.97	66.73

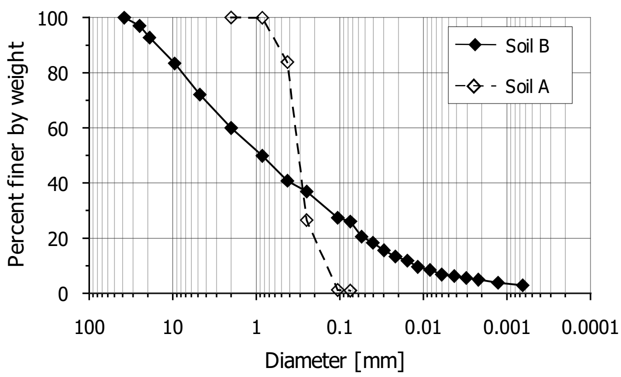

Figure 1. Particle size distribution curves of soils used in the research.

Two granular soils (Soil A and Soil B) were used in these tests. Each soil was tested for the main geotechnical parameters.

The results of classification tests indicate that the soil A is a uniform medium sand (A-3 according to CNR-UNI 1006 classification system), with uniformity coefficient $U=D_{60}/D_{10}=1.5$ and average grain size $D_{50}=0.22$mm. The Standard Proctor compaction test performed 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 and the lower values refers respectively to the lower (σ'_v=10kPa) and higher (σ'_v=100kPa) confining pressures. The shear strength angle at constant volume ϕ'_{cv} results equal to 34°.

The results of classification tests indicate that the soil B is a gravel with silty sand (A-2-4 according to CNR-UNI 1006 classification system), with an average grain size $D_{50}=0.85$mm. The fine fraction is non plastic. The Standard Proctor compaction test performed indicates a maximum dry unit weight γ_{dmax}= 21.55kN/m^3 at a water content $w_{opt}=6.2\%$. Large diameter C.I.D. triaxial tests (D=200mm, H=410 mm) performed at an initial unit weight equal to 98% of γ_{dmax} (obtained at a water content of 5.0%), yield very high single values of the peak shear strength angle ϕ'_p, in the range between 53° (σ'_c=50kPa) and 49° (σ'_c=100 kPa), while the shear strength angle at constant volume ϕ'_{cv} results equal to 38°.

More than 30 pullout tests have been performed varying the specimen length (L_R=0.40, 0.90, 1.15m) while keeping the specimen width constant (B=0.58m). Applied vertical pressures were equal to 10, 25, 50, 100kN/m^2. The displacement rate has been equal to 1.0 mm/min for all tests.

For each test condition, the friction between the clamp and the test soil has been evaluated by performing the test without the geogrid. The pullout force values for the clamp alone have been subtracted, at each displacement level, from the pullout forces measured in the tests with the geosynthetics at the same displacement.

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 maximum pullout force (pullout resistance) obtained in the tests is reported in Table 2.

Table 2. Pullout resistance, P_r (kN/m), measured in the tests.

Specimen Length (m)	Soil	Normal stress σ'_v			
		10 kPa	25 kPa	50 kPa	100 KPa
0.40	A	4.81	10.82	15.89	27.69
0.90	A	9.59	24.07	37.87	55.98
1.15	A	14.00	32.47	50.19	62.26 *
0.40	B	7.82	14.10	19.34	30.00
0.90	B	18.83	35.39	49.59	61.65
1.15	B	20.85	41.14	57.09	68.67 *

* Specimen failure

The figures 2 and 3 show the pattern of the pullout force versus the displacement of the specimen at the edge connected to the clamp. In details, Fig. 2 refers to tests performed on the longest specimens (L_R=1.15m), while Fig. 3 refers to the shortest specimens (L_R=0.40m). In both cases the curves on the graphs are referred to the different confining pressures and the different soils used in the testing program.

Analysing the pattern of the pullout curves, it is evident that the interface behaviour is strongly influenced by the embedded geogrid length for both the soils used. In fact, in both cases, tests performed on "long" specimens (L_R=1.15m) show a strain hardening behaviour, with a progressive increase of the pullout resistance with the increase of the displacement; while tests on "short" specimens (L_R=0.40m) show a strain softening behaviour, with a progressive decrease of pullout resistance after the peak. It is therefore possible to say that the pullout interaction mechanism is progressively developed along the "long" reinforcement specimens, while it is developed almost at the same time along the whole length of "short" specimens. In this latter case the pullout curves shows a pattern similar to stress-strain curves of compacted soils.

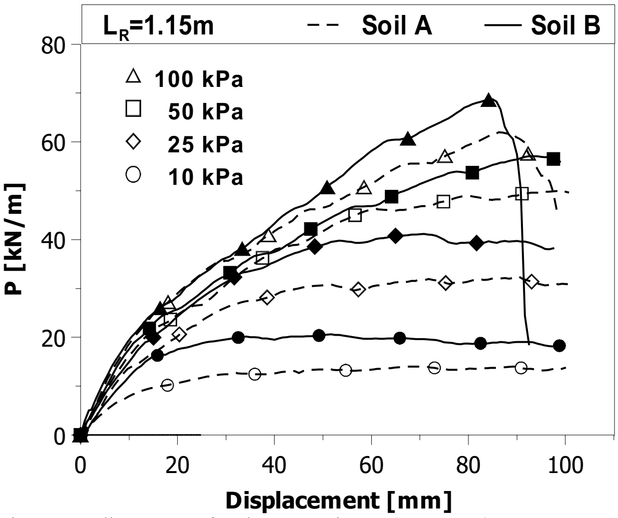

Figure 2. Pullout curves for "long" specimens (L_R=1.15m).

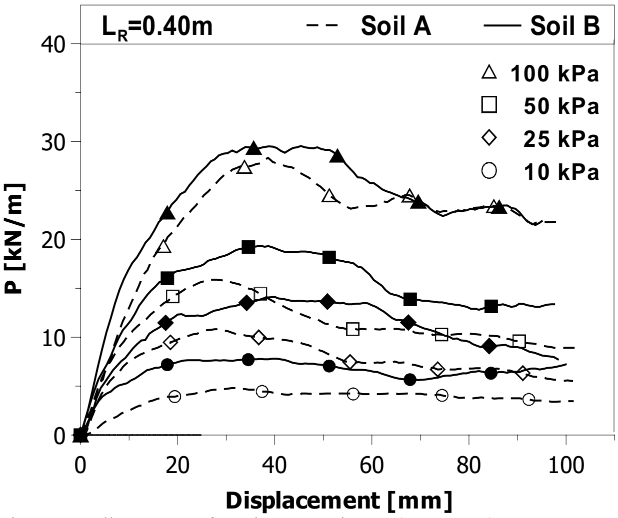

Figure 3. Pullout curves for "short" specimens (L_R=0.40m).

The influence of the type of soil can be enhanced by comparing the continuous line curves (soil B) with the dotted lines curves (soil A). These curves shown that the higher pullout resistance are obtained with soil B. This result can be explained when considering that pullout forces are the integrals of the tangential stresses mobilized on the interface, along the active length (that is the geogrid length in the anchorage zone). Such tensions, at equal length, structural characteristics, shape, resistance and stiffness of the reinforcing layers, depend on the shear strength properties of the soil in contact with the reinforcement.

Fig. 4 shows the results of the pullout tests in terms of the apparent coefficient of friction between soil and geosynthetic, $\mu_{S/GSY}$, calculated according to the following equation :

$$\mu_{S/GSY} = f_{po} \tan\phi' = \frac{P_R}{2 L_R \sigma'_v} \quad (1)$$

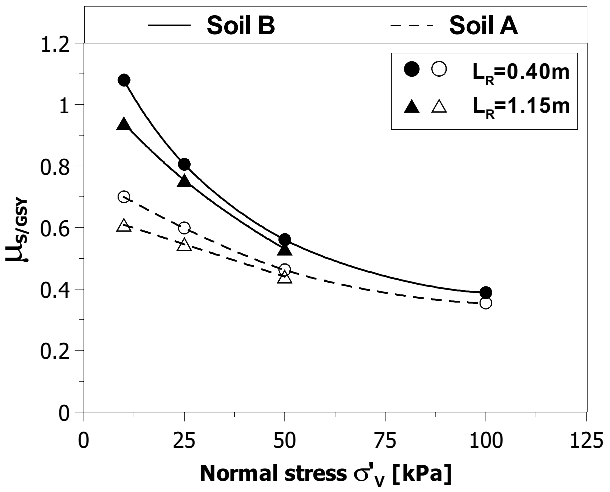

Figure 4. Interface apparent coefficient of friction in pullout tests.

The graph shows the pattern of the apparent coefficient of friction at the interface versus the confining pressure, for both soils A and B, and for both "long" specimens (L_R=1.15m) and "short" specimens (L_R=0.40m). In all cases a decrease of the apparent coefficient of friction mobilised at the interface with the increase of the confining pressure can be noted. It can be observed as well that the lower values are always associated with "long" specimens.

These results are due to two phenomena: the first one, and the most important, is related to the dilatancy effects, which tend to decrease with increasing applied pressures; the second one is related to the extensibility of the reinforcement, which influence the distribution of the shear stresses along the interface.

Test results show that the difference in the apparent coefficient of friction mobilised at the interface, between low and high confining pressures, due to the dilatancy effects can be up to 177 % for soil B, and up to 100 % for soil A.

The effect of reinforcement extensibility can be enhanced by comparing, at equal confining pressure, the apparent coefficient of friction evaluated for long specimens with those related to short specimens. It can be noted that the higher values of the apparent coefficient of friction refers to "short" specimens; the difference with the apparent coefficient of friction values related to "long" specimens, for low confining pressure (σ'_v=10kPa), is equal to 14.9%, for soil B, and to 14.7% for soil A. For higher confining pressure (σ'_v=50kPa) the difference becomes 5.7% for soil B, and 4.5% for soil A.

For all tests, analysing the figures showing the displacements along the specimen for different applied tensile forces, it is possible to observe the two different phases that characterise the pullout of the reinforcement from the soils: first the tensile force is progressively transferred to the geogrid until the whole embedded length become under tension and also the last point of the geogrid start to be displaced; in the second phase the pullout resistance increases until a peak (for "short" reinforcements) or a maximum pullout force or a geogrid tensile rupture (for "long" specimens) is reached. In details, for both soils there is a non-linear distribution of the displacements for "long" geogrid specimens (L_R =1.15m), hence a markedly non linear interface behaviour, due to the deformability of the reinforcement and to the various other factors affecting interaction between soil and open grid structures (Moraci and Montanelli, 2000). With "short" layers (L_R=0.40m), for both soils, after the "loading" phase, displacements become practically constant along the geogrid, showing a similar behaviour to very stiff reinforcing elements like steel bars.

For better illustrating the above concepts, figures 5 and 7 show the beginning of pullout, while figures 6 and 8 show the pullout phase, for both long and short specimens, for a single confining pressure. Similar graphs can be obtained for all other confining pressures.

The difference in the apparent coefficient of friction with varying specimen length is therefore due to the fact that with "long" specimens the pullout interaction mechanism is progressively developed along the reinforcement, see figures 5-6, while it is developed almost at the same time along the whole length of "short" specimens, as shown in figures 7-8.

Hence, in pullout conditions, for "long" specimens the shear stress at the interface results in the middle between the peak value and the constant volume value. On the other hand, for "short" specimens the shear stress at the interface is almost uniform and very close to the peak value, similarly to what can be observed with inextensible reinforcement.

Besides, in all tests it was observed that the higher apparent coefficient of friction values are obtained with soil B, having better shear strength properties than soil A.

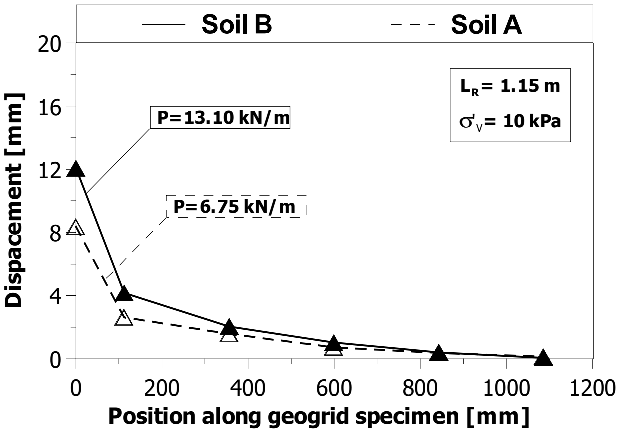

Figure 5. First phase: tensile force transfer: "long" specimen.

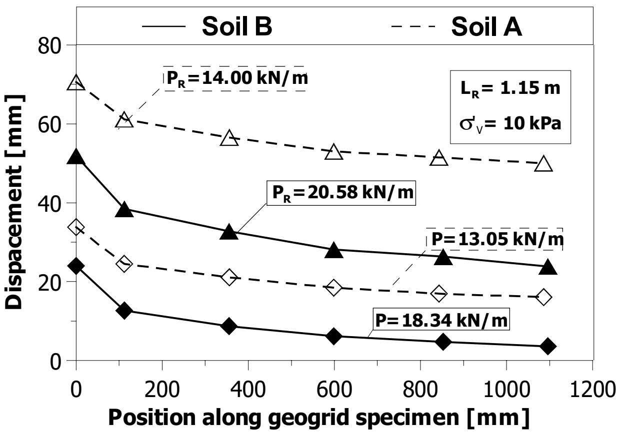

Figure 6. Second phase: pullout: "long" specimen.

The effects of dilatancy can be better noted in the diagrams in figures 9 and 10, which show the pullout resistance, with both soils, versus the specimen length and the confining pressure.

The curves that interpolate the experimental data show a marked curvature, similar to the typical Mohr-Coulomb failure envelope of granular dense soils (dilatant behaviour).

The largest curvature of the curves is observed with short specimens, where, in pullout conditions, a uniform distribution of shear stresses is mobilised (Moraci & Montanelli, 2000; Ghionna et al. 2001), that can be associated with the peak value of the shear strength angle.

The curvature decreases with the increase of the specimen length, due to the non linear distribution of the shear stress along the interface, that may be associated with values of the shear strength angle that are intermediate between the peak one and the constant volume one.

These diagrams also show three asymptotic values, related to the tensile strength of the geogrid, tested at different strain rate in wide width tensile tests according to EN ISO 10319 standard, and to the Long Term Design Strength T_D of the geogrid derived from creep tests in air. Such curves, when obtained for different combinations of soil and reinforcement, could be useful for design of reinforced soil structures, when the embedded length needed to mobilise the required strength shall be determined.

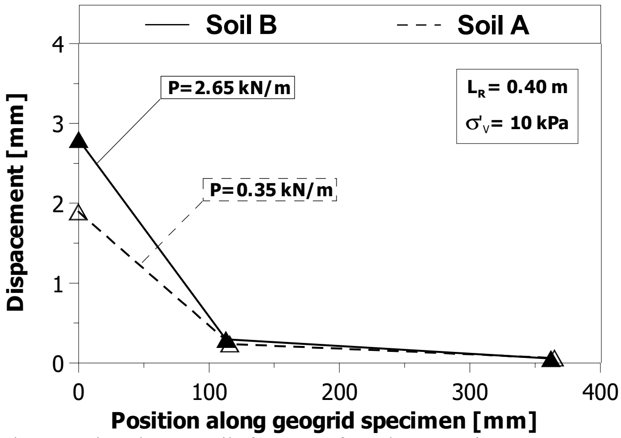

Figure 7. First phase: tensile force transfer: "short" specimen.

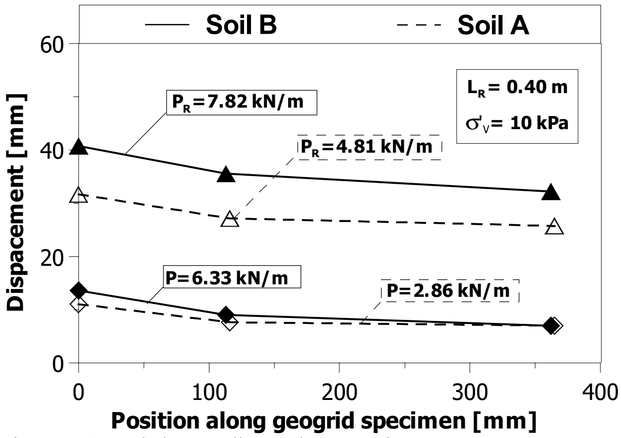

Figure 8. Second phase: pullout: "short" specimen.

3 CONCLUSIONS

The main conclusions of the present paper are the following:

a. experimental results clearly show the effects of dilatancy at the soil – reinforcement interface, for both the tested soils. Dilatancy effects occur along the three-dimensional failure surfaces, which start at the transversal bars of the geogrid due to passive wedges. Such effects influence the apparent coefficient of friction mobilised in pullout conditions, which increases with decreasing confining pressure, hence with increasing dilatancy effect. Due to dilatancy effect, the apparent coefficient of friction mobilised at low confining pressure can be higher than at high confining pressure. For the soils used in the research the largest difference were up to 177 % for soil B, and up to 100 % for soil A.
b. The extensibility of reinforcement influences the distribution of shear stresses at the interface; the non linearity of such distribution increases with increasing reinforcement length. On the other hand, the shear stress is almost uniform with "short" reinforcement, which tends therefore to behave like an inextensible reinforcement. With "long" reinforcement the shear stress mobilised at the interface may be associated with a shear strength angle in between the peak value and the constant volume value. With "short" reinforcement the shear stresses may be instead associated with peak values of the shear strength angle.
c. The design of the embedded length of reinforced soil structures based on constant volume values of the shear strength angle represents therefore a conservative assumption, particularly for the top reinforcement layers, where the confining pressures are low.

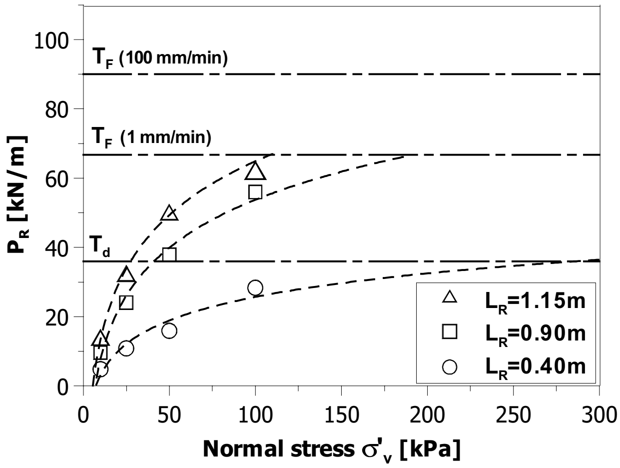

Figure 9. Pullout Resistance envelope curves: Soil A.

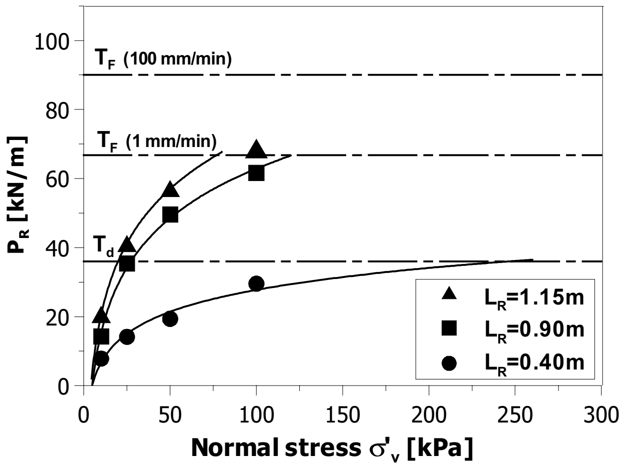

Figure 10. Pullout Resistance envelope curves: Soil B.

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