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Pullout resistance of extruded geogrids embedded in a compacted granular soil

Résistance de pull out de géogrilles incluse dans les sols granulaires compactées

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ABSTRACT
In order to study the pullout behaviour of reinforcement geogrids embedded in granular compacted soils, a new large scale pullout test apparatus has been designed. The layout of the apparatus has been studied after a careful study of similar tests performed by other researchers in order to define a device that could reproduce, as close as possible, the real situation. More than 40 pullout tests have been performed, at constant displacement rate (1.0 mm/min), on three different HDPE extruded mono-oriented geogrids embedded in a compacted granular soil varying the specimen lengths and the applied vertical effective confining pressures. The different geogrids used in the research have been tested with tensile tests performed at different speeds, and in particular at the same speed of the pullout tests, and the granular soil have been characterized through classification, Proctor and shear tests.
The pullout test results showed the influence of dilatancy phenomena and of reinforcement extensibility on the peak and the residual pullout resistance.

RÉSUMÉ
Pour étudier la résistance de pull out et le mécanisme d'interaction de le renforcement des geogrids dans les sols granulaires compactées, un grand nouvel appareil de pull out a été projeté. Le schème de l'appareil a été mis a point depuis l'étude de essais similaires fait d'autres chercheurs pour définir la condition que peut reproduire les réelles conditionnes. Plus que 40 essais de pull out ont été réalisée, à vitesse constante (1.0 mm/min), sur trois tipes de géogrilles dans le sols granulaires compactées, en variant la longueur du renforcement et la contrainte verticale.
Les renforcements utilisés ont été testés avec essais de traction avec différentes vitesses de déformations et, particulièrement, avec la même vitesse des essais de pull out. Les sables utilisées ont été caractérisée en faisant essais Proctor et de cisaillement direct. Les résultats montre l'influence des différents paramètres études sur la résistance de pull out maxime et résiduelle.

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 should reproduce, as close as possible, the actual conditions that a geosynthetic undergoes when embedded in soil in a reinforced soil structure.

In order to analyse the internal stability of reinforced earth structures, it is necessary to evaluate the reinforcement pullout resistance, mobilized in the anchorage zone.

The pullout resistance can be evaluated by pullout tests or by means of the following equations:

$$P_R = 2 \cdot L \cdot \sigma'_V \cdot f_b \cdot \tan\phi' \quad (1)$$

$$P_R = 2 \cdot L \cdot \sigma'_V \cdot \mu_{S/GSY} \quad (2)$$

where: P_R = Pullout resistance (per unit width); L = reinforcement length in the anchorage zone; σ'_V = effective vertical stress; ϕ' = soil shear strength angle; f_b = soil-geosynthetic pullout interaction coefficient; $\mu_{S/GSY}$ = soil-geosynthetic interface apparent coefficient of friction.

The soil-geosynthetic pullout interaction coefficient f_b may be determined by means of theoretical expressions: however different researchers (Palmeira and Milligan, 1989; Moraci and Montanelli, 2000; Ghionna et al., 2001) have shown how the values of f_b obtained by theoretical expressions are largely influenced by the choice of the value of the soil shear strength angle.

In absence of a clear indication regarding the choice of the soil shear strength angle to be used for the determination of f_b or of the development of new theoretical expressions that include the evaluation of all the parameters that influence the mobilization of the interaction mechanisms (frictional and passive), the problem of the determination of the pullout resistance may be overcome by the use of the soil-geosynthetic interface apparent coefficient of friction determined by means of large scale pullout tests, using the following expression:

$$\mu_{S/GSY} = \frac{P_R}{2 \cdot L_e \cdot \sigma'_V} \quad (3)$$

where: L_e = confined specimen length.

It is important to note that the determination of $\mu_{S/GSY}$ by using equation (3) can be performed without any assumption about the values of the soil shear strength angle mobilized at the interface, since all the parameters of the above equation can be easily determined from the pullout tests.

In the present paper some results of an experimental research carried out in order to study the factors affecting the pullout resistance of extruded geogrids are shown.

2 PREVIOUS EXPERIMENTAL STUDIES

A pullout test apparatus is composed by a rigid pullout box, a vertical load application system, an horizontal force application device, a clamping system, and all the required instrumentation.

Beyond the main features that are common for every testing apparatus, there are important differences that can affect the results: boundary conditions at top surface of the soil specimen;

boundary conditions at the front wall; friction between side walls and soil; pullout box dimensions; clamping device.

The soil specimen is usually confined in a large box with rigid base and lateral walls. The vertical confining stress can be applied by means of a rigid load distribution plate in contact with the soil or by means of a flexible membrane (usually rubber) filled with liquid or gas (air bag). The second system guarantees uniform normal stresses and the possibility of free vertical displacement in every point of the contact area.

The influence of the boundary conditions at the front wall was studied by many authors; Palmeira and Milligan (1989) have demonstrated how the apparent friction angle mobilized at the interface increase with the interface friction angle δ between the front wall and the fill soil. Moreover, the influence of the stiffness of the front wall is lower for big pullout boxes and for boxes having a bigger distance between the first confined section of the specimen and the front wall.

In order to avoid front wall effects the first confined section of the reinforcement specimen is moved to a suitable distance from the front wall by means of metal sleeves fixed to the front wall.

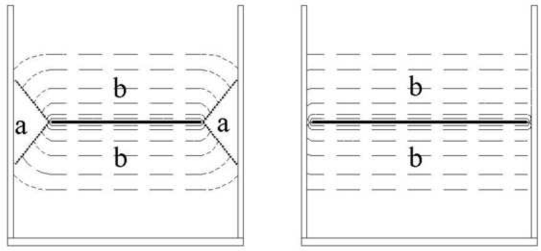

Figure 1. Scheme of the interaction for narrow and wide specimens.

Some indications on the choice of the proper height of the pullout box for open mesh geosynthetics (geogrid or metallic meshes) are given by Moraci and Montanelli (2000); according to the authors, the maximum size of the passive wedge can be taken as 40 times the thickness of the transversal rib of the geogrid.

Another important topic is the configuration of the clamping device that is necessary to apply the pullout tensile force.

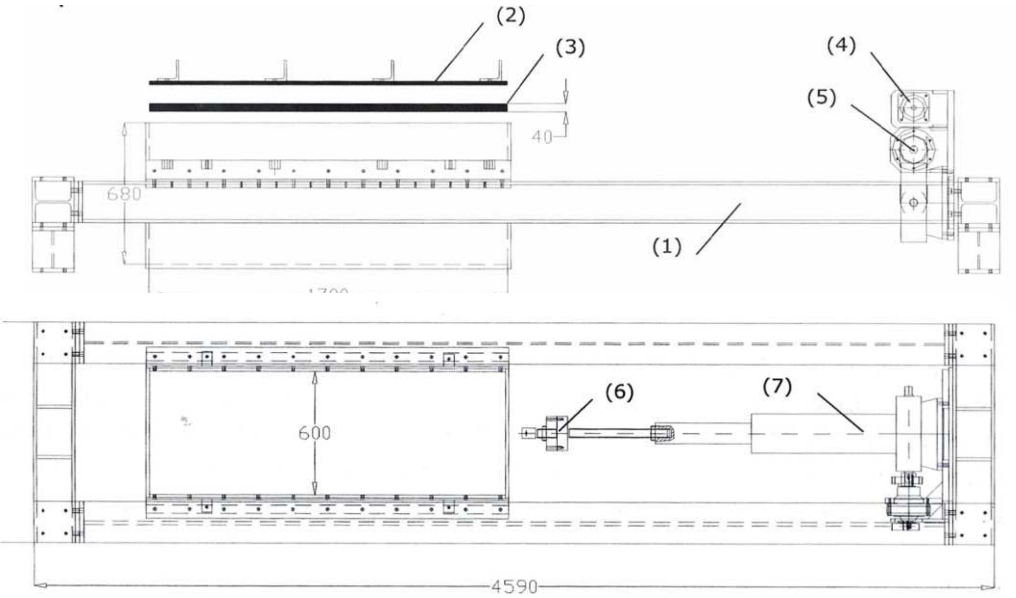

Figure 2 Scheme of pullout test apparatus: 1) frame; 2) steel plate; 3) air bag; 4) electric engine; 5) reducer; 6) load cell; 7) electric jack.

Another important aspect are the boundary conditions on the side walls of the pullout box. The effective vertical confining stress is due to the normal stress applied on the top soil specimen and to the weight of the of soil above the interface, the friction developed along the lateral walls of the pullout box can lead to confining stresses lower than expected.

In order to minimize the friction effects at the side walls low friction materials glued to the walls are used.

Theoretical and experimental studies carried out by Hayashi et al. (1996) and by Ghionna et al. (2001) have shown that for reinforcement specimens having a width smaller than the pullout box the soil dilatancy develops a three-dimensional effect. The non dilating zone (zone a in Fig.1) behave as a restrain against soil dilatancy in the dilating zone (zone b in Fig.1). This generates shear stresses between the two zones and produces an increase of the effective normal stress.

The effect of a given type of boundary condition is strictly connected with the pullout box dimensions: however, there are no clear indications about the suggestible box dimensions in literature. The effect of a given type of boundary condition is strictly connected with the pullout box dimensions: however, there are no clear indications about the suggestible box dimensions in literature.

Clamping system can be either outside the pullout box or inside it. With the second system the clamping device is inserted for a given depth into the test box, in order to guarantee a total confinement of the reinforcement during the test.

An internal clamping device has two main advantages: first of all the anchorage length is constant for the whole duration of the test; second, the displacement measured in correspondence of the clamping device are exactly the displacement of the first confined section of the geogrid (assuming that no relative movement can occur within the clamp), and can therefore been used directly in the test interpretation.

3 EXPERIMENTAL RESEARCH

3.1 *Testing apparatus*

The test apparatus is composed by a pullout box (1700x600x680 mm), a vertical load application system, a horizontal force actuator device, a special clamp, and all the required instrumentation, figure 2.

The pullout box consists of steel plates welded at the edges; an air filled cushion, restrained at the upper part form a steel plate, applies the vertical load.

Pullout force is applied by means of an electric jack; a load cell placed between the electric jack and the clamping system is used to measure forces.

The equipment incorporates two sleeves near the slot at the front of the pullout box in order to avoid front wall effects; the clamping device is placed inside the soil, well beyond the sleeve thus to keep the geosynthetic specimen always confined in the soil for the whole test duration.

Friction between the soil and the side walls of the box is minimized by use of smooth Teflon films.

Displacements have been measured and recorded through inextensible steel wires connected to the geogrid specimen. The wire gages were connected to displacements transducers (RVDTs) fixed to the external back side of the box.

All the instrumentations are linked to a personal computer that is programmed to scan the measurements at constant time intervals to perform the electronic control and the data acquisition system.

3.2 *Tested materials*

Pullout tests have been performed on three different HDPE extruded mono-oriented geogrids (respectively described as GG1, GG2 and GG3).

The mechanical properties of the different geogrids were evaluated by wide width tensile tests (EN ISO 10319) performed at different displacement rates of 1 and 100 mm/min. These speeds are respectively the pullout test rate and the wide width tensile test rate. The tensile test results at 1 mm/min displacement rate are reported in Table 1.

Table 1 Tensile stiffness and strength of the different geogrids at 1 mm/min displacement rate

Geogrid	$J_{2\%}$ (kN/m)	$J_{5\%}$ (kN/m)	T_F (kN/m)
GG1	946.5	719.5	73.06
GG2	1338.5	1049.0	98.99
GG3	1903.0	1354.8	118.29

Tested fill material was a uniform medium sand with uniformity coefficient $U=d_{60}/d_{10}$ =1.5 and average grain size d_{50}=0.22 mm; the Maximum dry unit weight measured after Standard Proctor compaction test was γ_{dmax}=16.24 kN/m^3 with w_{opt}=13.5%.

Direct shear tests performed at 95% of γ_{dmax} (obtained at a water content of 9%), yield values of the peak shear strength angle ϕ'_p, in the range between 48° and 42°.

The shear strength angle at constant volume ϕ'_{cv} was equal to 34°.

4 EXPERIMENTAL RESULTS

More than 40 pullout tests have been performed varying the specimen length (L_R= 0.40, 0.90, 1.15 m) while keeping the specimen width constant (W= 0.58 m). Applied vertical effective pressures were equal to 10, 25, 50, 100 kN/m^2. The 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 was achieved. For all the tests, the geogrid specimens remained always confined within the soil for its whole length.

By means of pullout test it is possible to evaluate the peak pullout resistance P_R, corresponding to the maximum value of pullout force measured in the test, and the residual pullout resistance P_{RR}, corresponding to the ultimate value of pullout force at large displacements. Table 2 summarize the test results

From the data in Table 2 it is possible to notice that the reduction in pullout resistance from peak to residual value depends on the confining stress and on the geogrid length. In particular, the largest reduction are observed for short specimens under low confining stresses.

In order to analyse the influence of the anchorage length, pullout curves have been normalized respect to L_R (Fig.3). From the analysis of these curves it can be observed that "short" reinforcements (L_R = 0,40) develop a greater normalised resistance respect to longer reinforcement.

Table 2. Peak (P_R) and residual (P_{RR}) pullout resistance (kN/m) measured in the tests.

	L (m)	Normal stress σ'_v							
		10 kPa		25 kPa		50 kPa		100 KPa	
		P_R	P_{RR}	P_R	P_{RR}	P_R	P_{RR}	P_R	P_{RR}
GG1	0.40	9.62	5.63	20.26	13.29	30.95	18.93	39.79	26.43
GG1	0.90	16.62	12.14	34.55	29.79	52.53	50.34	78.44*	-
GG1	1.15	20.00	14.76	37.13	34.32	62.79	62.79	72.48*	-
GG2	0.40	13.42	8.44	24.76	15.43	41.18	24.04	56.59	37.51
GG2	0.90	21.32	15.43	39.99	32.14	70.07	62.46	103.91	103.91
GG2	1.15	26.96	19.53	51.43	44.00	75.62	75.62	106.91*	-
GG3	0.40	12.84	7.36	22.72	13.64	37.68	25.18	58.68	49.04
GG3	0.90	19.85	15.48	41.80	34.69	72.95	61.27	97.59	97.59
GG3	1.15	24.35	19.61	47.75	43.79	81.77	81.77	115.19	115.19

*Specimen failure

These differences are more evident for peak pullout forces, while in ultimate conditions the P/L_R values seem to be independent on the reinforcement length. These results show the influence of the specimen length, and therefore of the extensibility of the reinforcing element, on the pullout behaviour, particularly at the peak conditions.

To enhance the influence of the vertical confining stress on the pullout behaviour the pullout curves for geogrid GG1 have been normalised respect to $\sigma v'$ (Fig.4).

From these charts it is possible to notice an important reduction in the normalized resistance passing form low to high confinement stress, both in peak and residual conditions.

The experimental results can be explained by means of soil dilatancy phenomena that develop in correspondence with the three-dimensional passive failure surfaces that arise at the node embossments and at geogrid transversal bars.

Due to these phenomena, whose entity decreases with the increases of the confining vertical effective stress, two main effects develop: the first is due to the different work necessary to expand the dilatancy surface at different vertical effective confining stresses; the second effect is due to the restriction of the dilatancy connected to the nearby soil stiffness (constrained dilatancy), which yields a local increment of the effective confining stress.

5 CONCLUSIONS

The test results clearly show the influence of the different parameters studied (embedded length and vertical effective stress) on the pullout resistance of extruded geogrids embedded in a granular soil. In particular, the main conclusion are the following:

- The tensile failure values in pullout conditions are very close to the tensile strength obtained by in air tests performed at the same rate of the pull-out tests. This means that, the influence of soil confinement on reinforcement tensile strength is negligible.

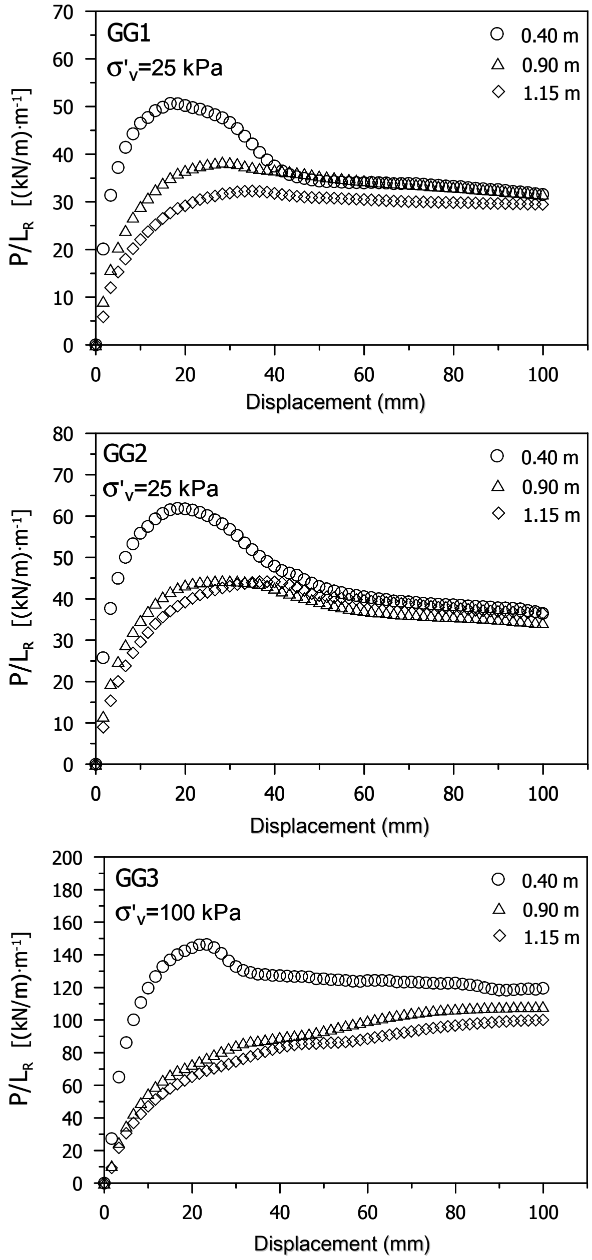

Figure 3. Normalized pullout curves (P/L_R) for the different geogrids.

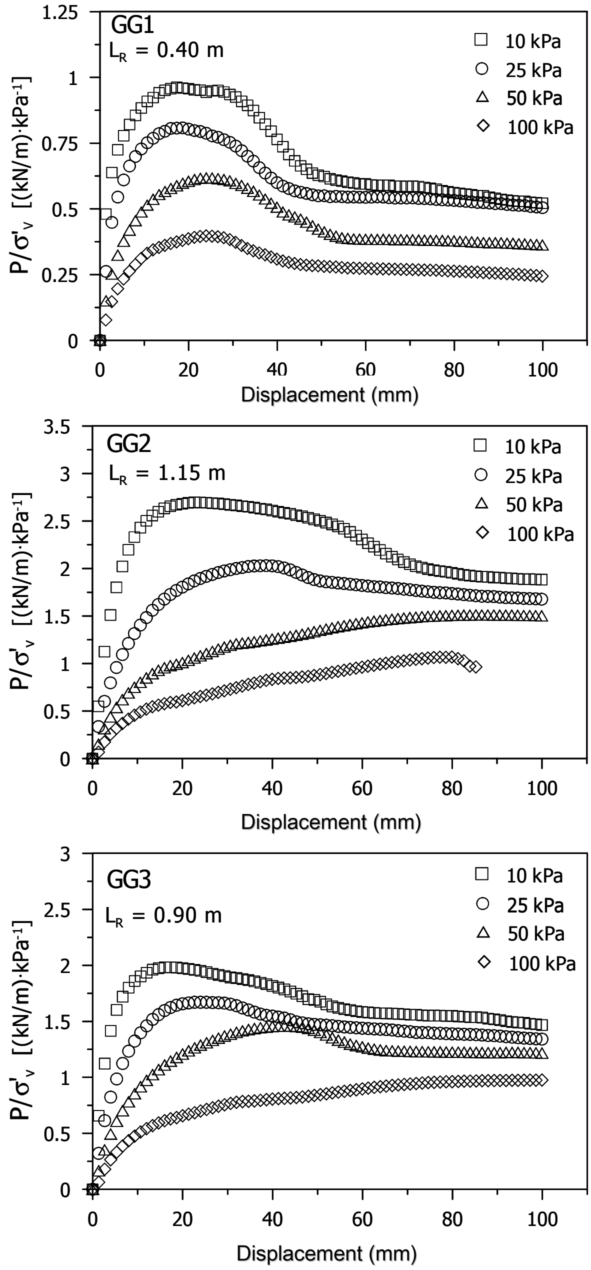

Figure 4. Normalized pullout curves (P/σ_v') for the different geogrids.

- The phenomena that have the largest influence on pullout resistance is the dilatancy of the soil at the interface. Due to the dilatancy effects the pullout strength mobilized, for the same reinforcement length, at low vertical effective confining pressure (10 kPa) is higher than at high confining pressure (50 or 100 kPa). The dilatancy phenomena develop in correspondence of the passive failure surfaces, which are generated in correspondence of the node embossment and of the geogrid transversal bars. The maximum percentage differences of pullout resistance (up to 150 %) due to the dilatancy effects, were observed for the "short" reinforcement specimens (L_R=0.40 m).
  The experimental results have also shown that the extensibility of reinforcement have an influence on peak pullout strength. In particular, extensibility effects are more evident for long reinforcements and for high confining stresses (up to 50%). In residual conditions the extensibility effects are negligible.

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