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BEHAVIOUR OF GEOGRID REINFORCED GRAVEL IN LARGE SCALE TRIAXIAL TESTS

INVESTIGATION DU LABORATOIRE SUR LA RESISTENCE A DECHIRURE DU TERRAINS REINFORCES AVEC GEOSYNTHETIQUES

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SYNOPSIS: A comprehensive knowledge of the mechanical behaviour of reinforced soils still poor due to the lack of well documented experience. In order to obtain more information a program of large scale triaxial tests on geogrid reinforced gravel has been carried out at the University of Naples.
The comparison of the results obtained on reinforced and unreinforced specimens shows a clear change in the behaviour, from strain-softening for the gravel alone to strain-hardening with limited horizontal deformation for the geogrid reinforced gravel.

INTRODUCTION

Since their introduction on the market, in the early '80, geogrids have quickly gained an important position in the geosynthetics family: actually, they are recognized as effective soil reinforcement products, thanks to the high tensile modulus and the capacity of interlocking with soil particles through the apertures of the grid.
Theoretically geogrids produce a strong confinement on soil particles and provide horizontal tensile forces at low deformation, which increase the shear resistance of the soil geogrids composite medium.
Unfortunately, well documented experiences about the actual behaviour of soils reinforced with geogrids are still lacking; this reduces the possibilities for a rational design of earth structures reinforced with these geosynthetic products.
Actually, while some information about the soil-geogrids have been obtained, showing that limited differences exist with the frictional characteristics of the soil alone (Laboratory Investigation On The Shear Strength Of Geosynthetic Reinforced Soils; Picarelli et al., 1993); few experiences analyse the overall behaviour of a reinforced soil mass.
In this paper the overall strength of reinforced soils has been measured by triaxial tests on large scale specimens, which have highlighted the role played by the reinforcing elements when placed normally to the maximum principal stress.
The present paper is part of a larger testing program, aimed to obtain detailed information on the frictional behaviour of geogrids and geotextiles.
A paper related to this testing program, including also direct shear and pull out tests, has already been presented (Picarelli et Al., 1993).
This paper is limited to the triaxial tests which, to the Authors' opinion, are the most interesting and promising for the geotechnical scientific community.

TESTED MATERIALS

Only a cohesionless soil has been used: a gravel, whose main characteristics are reported in Table 1, while the grain size curve is shown in Fig. 1. The soil come from glacial deposits in Northern Italy. The gravels are constituted by particles with slightly rounded edges.

Table 1 - Characteristics of the gravel used in the tests.

d_{10}	d_{60}	U_c	γ_s	γ_d	w	S	n	Proctor density
mm	mm	-	kN/m³	kN/m³	%	-	-	kN/m³
2	3	1.5	2.66	18.2	12.8	0.73	0.32	18.75

The geogrids used (produced in Italy) are Polypropylene biaxially oriented geogrids, called Tenax LBO 301 AMP.
The main mechanical parameters of the geogrid are reported in Table 2, while the stress-strain characteristics obtained in tensile tests are reported in Fig. 2.

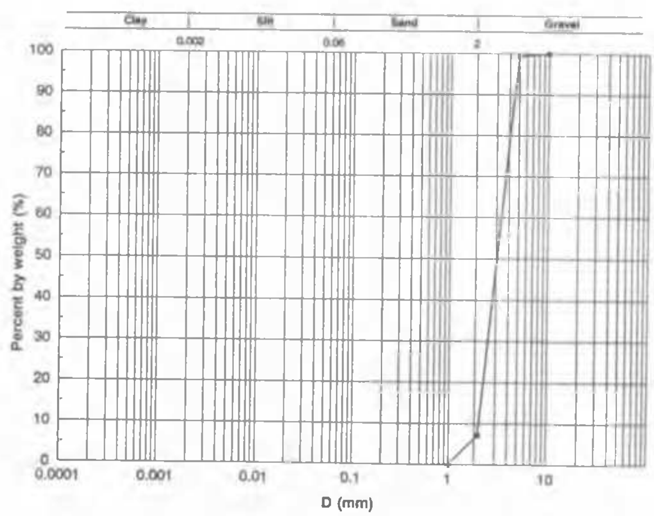

Fig. 1 - Grain size curves of the soils used in the tests.

Table 2 - Mechanical characteristics of Tenax LBO 301 AMP biaxial oriented integral geogrids.

Characteristics	Dir.	Standard	Value Unit
Wide width strip tensile strength	MD	ASTM D4595	19.5 kN/m
	TD		30.1 kN/m
Peak tensile strength (single rib)	MD	GRI GG1	19.5 kN/m
	TD		30.0 kN/m
Yield point strain (single rib)	MD	GRI GG1	20 %
	TD		11 %
Secant modulus at 2 % strain	MD	GRI GG1	285 kN/m
	TD		440 kN/m
Secant modulus at 5 % strain	MD	GRI GG1	180 kN/m
	TD		370 kN/m
Junction strength	MD	GRI GG2	18.0 kN/m
	TD		29.0 kN/m
Flexural rigidity	MD	ASTM D1388	850000 mg x cm
	TD		990000 mg x cm

Note: MD = Machine Direction (along roll length)
TD = Transversal Direction (across roll length)

TESTING PROGRAM

The testing program has been carried out at the Geotechnical Laboratory of the University of Naples where a number of CID triaxial tests on large scale specimens have been carried out [1].
These tests have been performed in a large apparatus having a diameter of 350 mm and a height of 820 mm. In this case the soil, reinforced with three layers of the Tenax LBO 301 AMP geogrids, installed horizontally respectively 205, 410 and 615 mm above the base, has been utilized.
The results have been compared with those obtained on the unreinforced soil.
All the specimens have been compacted by means of a vibrating table directly inside the membrane in order to reach a density of 18.2 kN/m^3.
During the test the volumetric deformations have been obtained by measuring the volume changes of the water contained in the triaxial cell.
The cell pressures varied between 50 and 400 kPa and the rate of displacement has been of 0.3 mm/min.

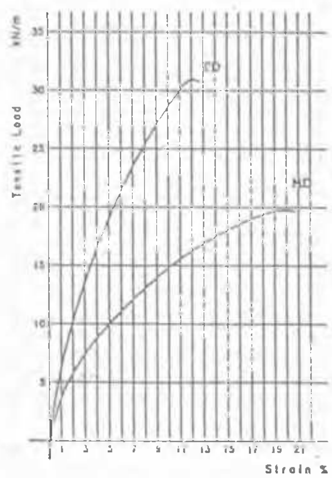

Fig. 2 - Stress-strain behavior in tensile tests of the biaxially oriented geogrids.

RESULTS OF TRIAXIAL TESTS

CID Triaxial tests

In the knowledge of the Authors only few triaxial tests have been conducted until now on large scale specimens reinforced with geosynthetics.
Broms [2] carried out several tests on geotextiles-reinforced soils, adopting small specimens (d=69 mm) of uniform sands and a variable number of fabric elements: according to his research, the geotextiles determine an increase of the overall strength, which is directly related to the spacing of the fabrics; furthermore he observed an increase of the peak axial strain of the reinforced specimens.
Similar tests have been described by Chandrasekaran et al. [3], who have investigated the influence of: i) the spacing between horizontal reinforcing geotextiles layers; ii) the cell pressure; iii) the stiffness and the strength of the geotextiles. The tests involved an uniform sand reinforced with woven and nonwoven geotextiles equipped with strain gauges; the specimens had a diameter of 100 or 200 mm and the cell pressure varied between 25 and 80 kPa.
The results of such an investigation show that both the spacing of the fabric layers and their stiffness affects the mobilised interface friction, hence the overall strength of the specimens. From these results, it may be inferred that the strength increase is due to an increase of the confining pressure in the soil between the fabrics.
Similar results have been reported by some other researchers [4, 5, 6].
The experimental program described in this paper has been carried out with 0.1 m^3 specimens of gravel reinforced with three layers of Tenax LBO 301 AMP biaxial geogrids.
By the tests the roles played by the reinforcements (namely the deformations restraining and the confining effects) may be inferred.

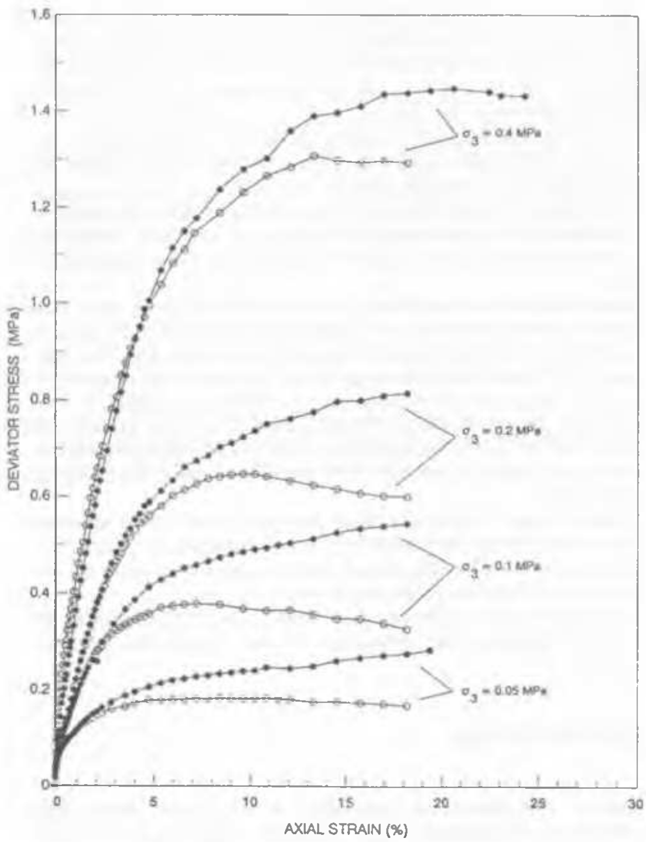

Fig. 3 - Stress-strain curves obtained in large scale triaxial tests

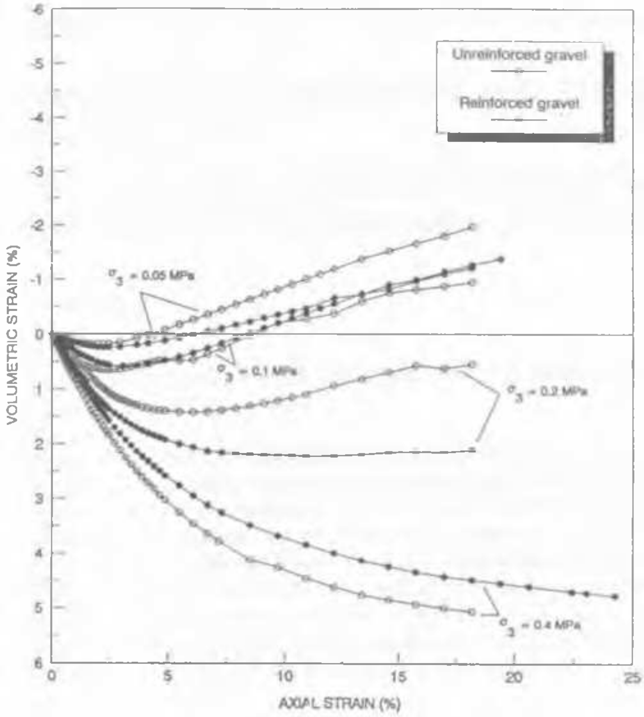

Fig. 4 - Volumetric strain vs. axial strain in large scale triaxial tests.

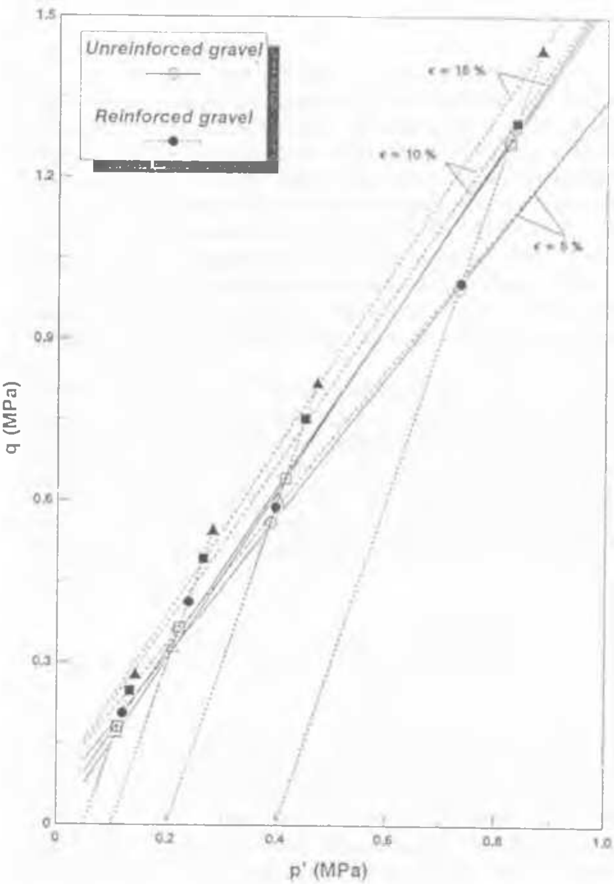

Fig. 5 - Stress paths and curves of equal axial strain

The stress-strain curves obtained on both unreinforced and reinforced specimens are reported in Fig. 3. It shows quite clearly that the influence of the geogrids is practically unrecognizable up to an uniaxial strain ranging between 2.5% and 5%, depending on the confining pressure, while for higher strains it determine a valuable increase of the strength.

Furthermore, the shape of the stress-strain curves of reinforced specimen is typical of a strain-hardening material, with a progressive increase of the strength due to the increase of the shear stresses along the interface with the geogrids; on the other hand, the unreinforced specimens are characterized by a strain-softening behaviour.

In other words, it appears that the gravel placed between the geogrids is subject to a stress path different from that featured by the unreinforced specimens, being characterized by higher octhaedral stresses, determining an increase of the strength and a more ductile behaviour.

With reference to the specimens subject to the extreme cell pressures, from Fig. 4 it seems that the geogrids determine a reduction of the volumetric strains, both for contractant and dilatant specimens.

Figure 5 shows the nominal stress paths, where the lines of equal strains are also indicated; the diagram shows once again that the effectiveness of the reinforcements increases with increasing strains.

In terms of conventional shear strength parameters, the reinforced specimens are characterized by a considerable cohesion (31 kPa versus the 9 kPa measured for unreinforced specimens), while the friction angle (about 38°) is practically the same for both the cases (Fig. 6).

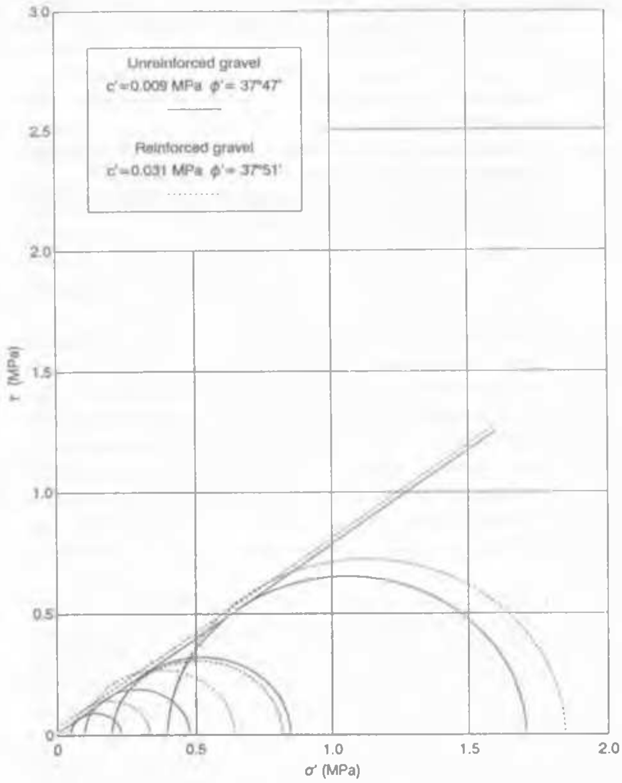

Fig. 6 - Failure envelopes of reinforced and unreinforced specimens in large scale triaxial tests

CONCLUSIONS

A laboratory investigation carried out on soils reinforced with geogrids allowed to obtain more information about the interaction between these different materials.

Some drained triaxial tests carried out on large specimens of gravel reinforced with three layers of a biaxially oriented geogrid have shown the modification of the mechanical behaviour up to failure due to the presence of the reinforcing elements and the increase of the overall shear strength of the reinforced materials, which get an apparent cohesion. However, the reinforcing effect of the geogrids is put into evidence only after rather high strains: this outlines the importance of the geosynthetic stiffness on the overall behaviour of the reinforced material.

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