Soil Reinforcement Interaction by In-Soil Tensile Tests and Direct Shear Tests

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ABSTRACT: The analysis of design parameters for geotextile reinforced structures requires the evaluation of the mechanical properties of the reinforcing elements as close as possible to field conditions. The same applies for the measurement of bond strength between soil and reinforcement for design purposes. These aspects were investigated by a large number of in-soil tensile tests and direct shear tests with different soils and geotextiles (woven and non-woven) and the main results are presented and discussed in this work. General models of interaction between soil and geotextile were established based on the results obtained by mechanisms associated with the mobilised shear stresses, soil volume variations and geotextile deformability. The effects of the confinement on the geotextile stress-strain response were analysed in terms of reorientation of the textiles fibres as a function of the reinforcement stiffness.

1. INTRODUCTION

In the context of soil reinforcement techniques, the performance of the associated materials is conditioned by interaction mechanisms between soil and reinforcement elements. The reinforcement action implies the incorporation of tensile stresses mobilised in the inclusions that results in a complete tension redistribution in the interface domains. In addition, it makes substantial changes in the global response of the structure in terms of stress-strain behavior.

In case of typically extensible inclusions such as geotextiles (woven and non-woven wraps from different makers and presenting different characteristics), the soil-reinforcement interaction laws are particularly complex, and governed basically by two dependent mechanisms: behavior due to interface shear and influence due to confinement of the soil over the mechanical characteristics of the geotextile (Mitchell e Villet, 1987). These behaviors have been investigated through an extensive experimental research program (Gomes, 1993) which allowed the characterization of general geotextile - soil interaction patterns, and an evaluation of interfaces parameters between standard soils and geotextiles made in Brazil.

2. EQUIPMENT AND SOIL - GEOTEXTILES INTERFACES.

In these studies, different soil types have been tested (crushed rock, gravel, pebble, sand, cohesive and lateritic soils, under different conditions of moisture content and compaction energy), as well as different woven and non-woven geotextiles made in Brazil. Considering the modeling advantages and the validity of direct shear tests in the interface parameters evaluation (Ingold, 1982; Bonaparte et al., 1987) standard procedures have been adopted in the experimental analysis.

In the shear strength studies of geotextile soil interfaces, a large direct shear equipment was built by associating large boxes (400 x 250 x 100 mm) with a normal stress application device. To define a general methodology a preliminary parametric analysis of the test was done (Gourc et al., 1990). This took into consideration the evaluation of the variables such as : gap between top and bottom halves of the shear box, soil layer thickness, geotextile anchorage conditions, etc.). Based on these principles, almost 350 tests were made and covered 76 different interfaces (selected by their kind of soil-geotextile-soil and soil-geotextile-rigid base arrangements).

The soil-geotextile interaction mechanism analysis included the development of a in-soil tensile device. This system was adapted from a large direct shear equipment and a device, which is activated by pumps and hydraulic jacks. The soil-geotextile sample, with dimensions of 200 x 100 mm, was reinforced in their edges with a very strong synthetic resin, and fixed in the reaction structure by a system of clamps. Similarly to the former case, the test methodology was implemented through a previous parametric analysis. These tests used similar interfaces which were previously analyzed in the process of direct shear. The shear tests used different granular soils: gravel (granulometry between 4.8 to 9.5mm e $\phi = 45°$), pebble (4.8 to 9.5mm and $\phi = 43°$), fine gravel (2.0 to 4.8 mm and $\phi = 38°$) and sands (0.6 to 2.0 mm and $\phi = 37°$ for loose sand, and $\phi = 41°$ for dense sand) and cohesive soils, which were prepared under different moisture content and compaction conditions. A soil composed of 99% of kaolinite and with granulometry 90% less than 60μm, maximum dry specific weight of 14.3 kN/m^3, and optimum moisture content of 27% (in this work, this soil was named as kaolinite) was tested with moisture contents of 28% and 34%, and in mixtures of 10% and 30% by weight with sand.

The strength parameters of these soils were obtained using the same direct shear tests procedure applied to the geotextile-soil interfaces. In the typical test arrangements, the textile membrane was inserted between two layers of the same soil, which were prepared under the same conditions. The test speed was 1,0 mm/min (enough to guarantee analyses under drainage conditions for all studied interfaces; for cohesive soils, the samples were consolidated under normal stresses (10, 50 and 100 kPa), before the shear stresses were applied. As a variation of the test, and in order to analyze the performance of a given interface under limit conditions, a series of tests were done with the granular materials sliding over a flat metal plate (rigid base), which was fixed in front of the lower shear box edge.

In the tensile tests, the experimental studies included analysis with the geotextile isolated and in presence of soil. In these cases, the confinement domain was represented by two thin soil layers which involve the geotextile (medium thickness of about 12,5 mm). It was formed by the alocation of grains in case of gravels and pebbles, and by pluviation in case of sand or silt. The test speed was 2% /min and the confining pressures were 10, 50 and 100 kPa.

Interfaces were tested involving woven and non-woven geotextiles made in Brazil. The woven geotextiles consist of textile membranes formed by a orthogonal arrangement of slit-film fibers and/or interlaced filaments in a planar fabric. They are commercially known as Propex. The types PR-2004 and PR-4004, of 167 and 157 g/m^2 mass per unit area, respectively, have been tested. The non-woven geotextiles, which were tested in the present studies, are textiles membranes composed of 100% polyester continuous filaments. They are commercially known as Bidim. OP-20, OP-30 and OP-60 types, of mass per unit area equal to 200, 300, 600 g/m^2, respectively, were tested. Table I shows the most important physical parameters of the geotextiles used in these studies.

3 SHEAR STRENGTH OF SOIL - GEOTEXTILE INTERFACES

The direct shear test results were interpreted, at first, taking into account the interface parameters ϕ_G (friction angle of the soil-geotextile interface) and c_G (soil-geotextile adherence). On the other hand these results were related to the confining soil shear strength parameters (c, ϕ) through the characterization of the so-called adherence and friction factors of a given soil - geotextile system which are defined by $a = c / c_G$ and $f = tg\phi / tg\,\phi_G$.

Table 1 - Physical Parameters of the Tested Geotextiles

Geotextile	t (mm)	μ (g/m^2)	T (kN/m)	ε_f (%)	F_T (kN)	p_B (MN/m^2)
OP - 20	2.1	200	15	30 - 35	1.12^a	2.2^c
OP - 30	2.6	300	22	30 - 35	1.70	2.9
OP-60	4.5	600	38	30 - 35	2.86	6.0
PR2004	0.25	167	22	10	0.30^b	3.6
PR4004	0.35	157	22	10	0.34	3.9

(a) AFNOR G 38015 (b) ASTM D 2263 (c) ASTM D 3786

Figure 1 represents these initial analysis and also shows that the friction coefficient, which is induced at the noncohesive soil interfaces, is usually very high. In addition, a certain effect of locking and blocking of granular soils similar to interlocking effects in sands, has been observed. For rough type geotextiles, the values of ϕ_G presented the same magnitude of ϕ; strictly speaking, only for sand (fine to medium) - geotextile PR-2004 interfaces, the f parameter was less than 0.90. This was due to the interlocking mechanism of soil particles in the textile matrix.

The grain angularity tends to intensify the blocking and locking effects, leading to the creation of greater shear stress

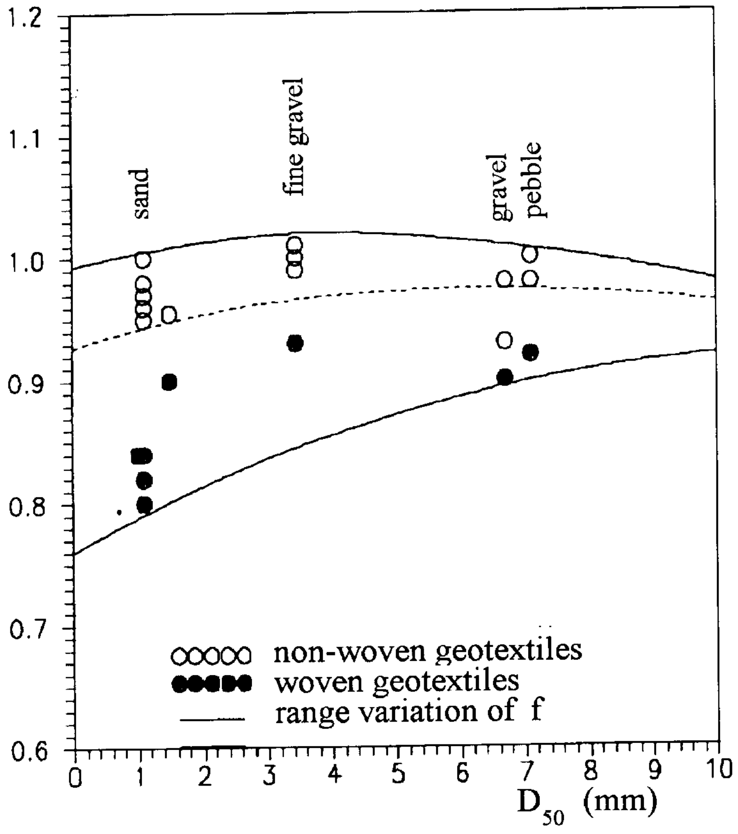


Figure 1 Range variation of friction parameters for granular soil - woven and non-woven geotextile interfaces.

on the interface. For the non-woven geotextiles, that interaction mechanism produced an apparent adhesion, which had little influence on the interface friction characteristics. This was not observed in the case of woven textiles. In the case of granular soils, the grain angularity and the geotextile fabric were primarily responsible for the apparent adhesion parameter.

In another stage of the present study, previous analysis were re-examinated on the ligth of the evolution of strength parameters with the displacements (named a* and f*), and based on the performance evaluation of a given interface, taking into account the variation between shear strengths in the soil-geotextile interface, and in the soil-soil interface (τ_G/τ) versus displacements, for a given normal stress. In the case of sand-geotextile interface, both interpretation criteria are potentially valid but important conclusions has been masked in the previous analysis which was based only on values of f.

Sand-geotextile interfaces were studied in three different compaction and moisture content conditions: loose sand (void ratio between 0.85 and 0.87; relative density of about 30%), medium dense and dry sand (void ratio between 0.74 and 0.75; relative density of about 50%), and medium dense and wet sand (prepared under similar conditions of the former sample) and moisture content of 21 ± 1%. Fig. 2 shows that both criteria are valid and highligths the best performance of geotextiles in dense dry sand interfaces. Besides, it is shown that for the sand-geotextile interfaces, shear behavior is more susceptible to moisture content variations than soil compaction effects.

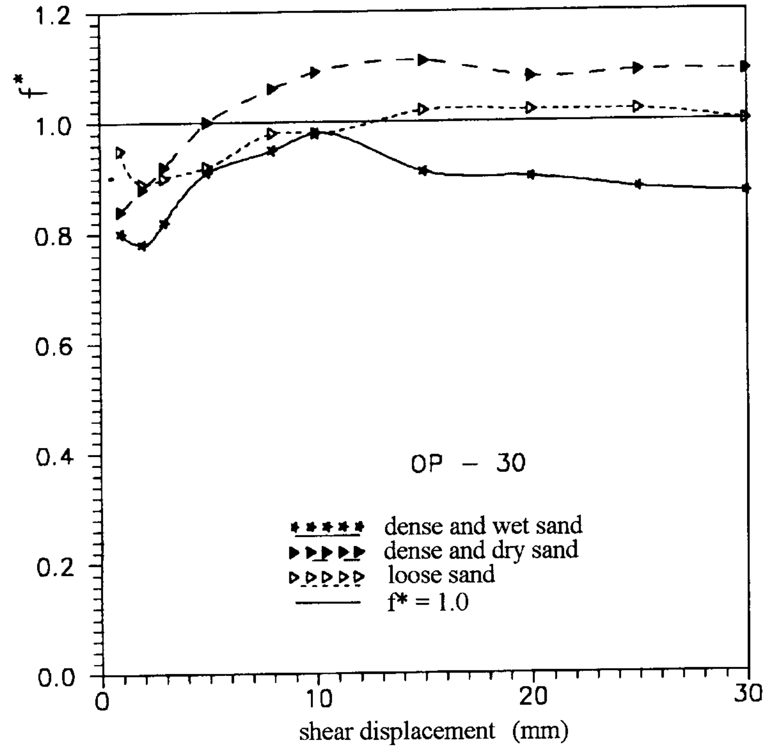


Figure 2a. Variation of interface parameters f* with the displacement of the sand - non-woven geotextile interface.

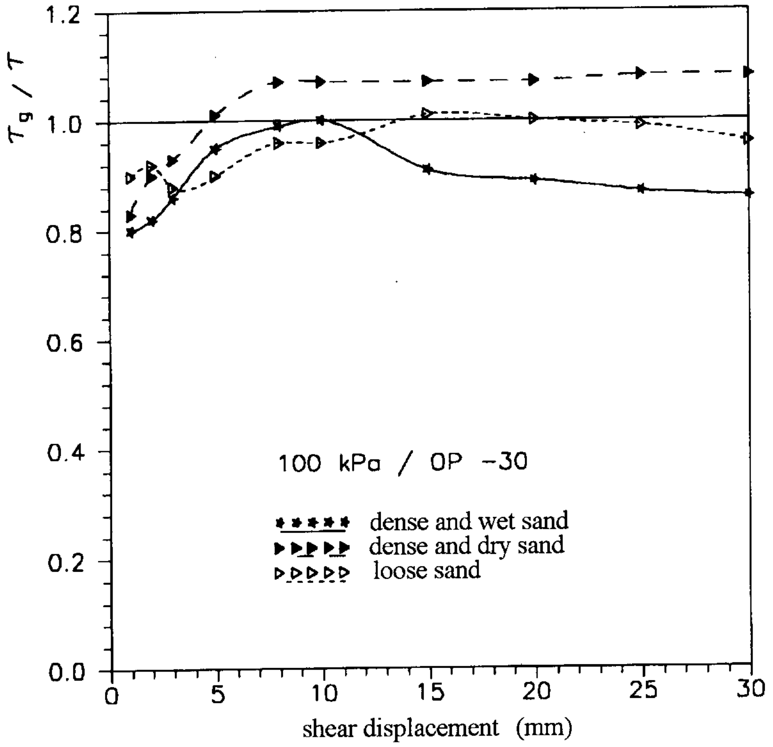


Figure 2b Variation of interface parameters τ_G/τ with the displacement of the sand - non-woven geotextile interface.

Performance analyses of geotextile and cohesive soil interface shows a domination of the interaction by adhesion under low confining stresses and by friction under high confining tensions. The relation f x δ, in this case, was quantitatively different from the relation τ_G/τ x δ (fig. 3),

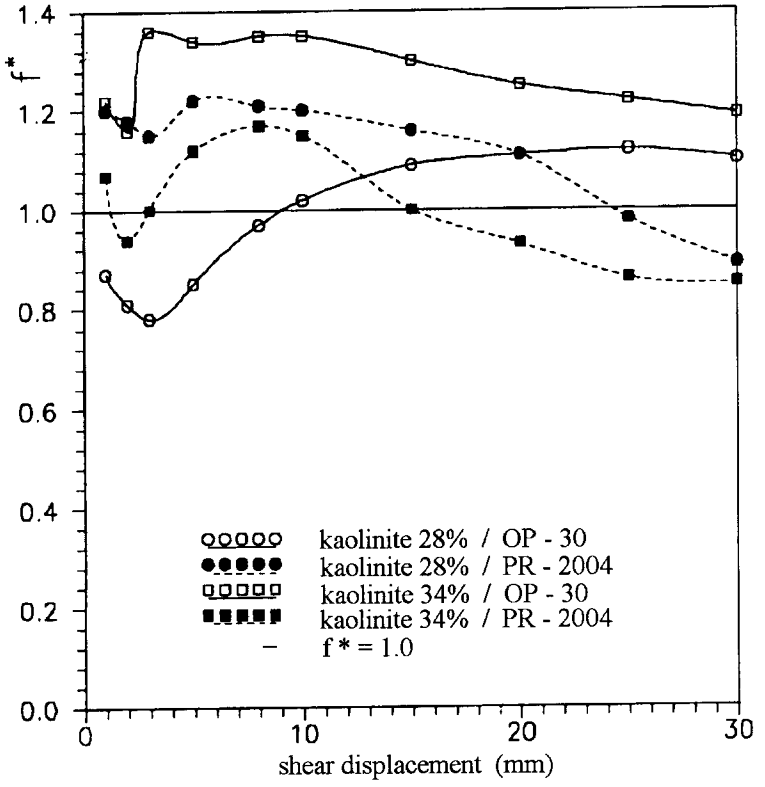


Figure 3a. Variation of the parameters f* with the displacemen of kaolinite-geotextile interfaces.

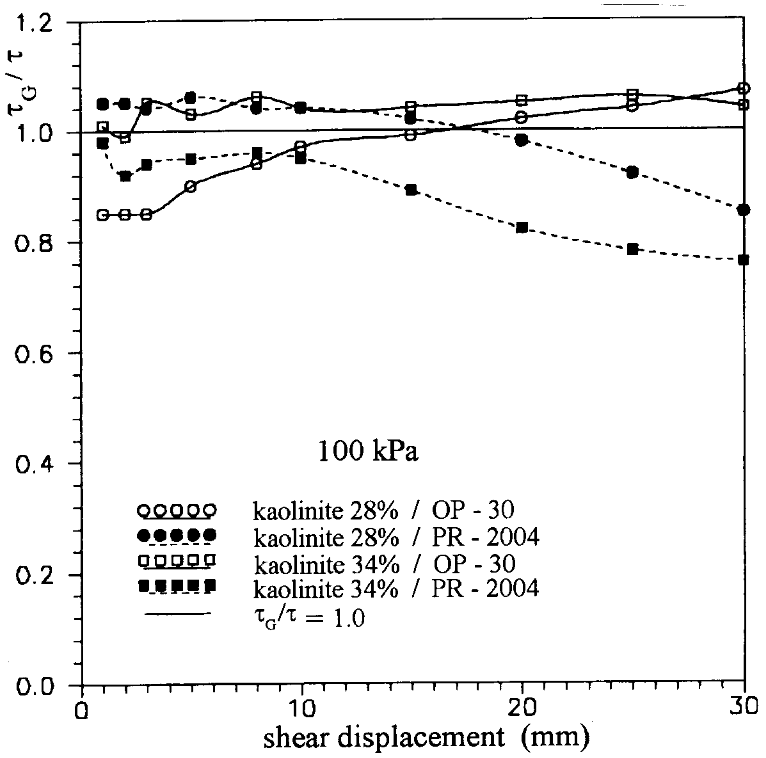


Figure 3b Variation of the parameters τ_G/τ with the displacement of kaolinite-geotextile interfaces.

contrary to what was observed with sand interfaces. In this context, the interpretation, which is based on the $\tau_G/\tau \times \delta$ relation, is more physically consistent because it separately embodies adhesion, and interface friction.

In the following analysis stage, the test kinematics was investigated taking into consideration the evaluation of the rotating effects on the sample inside the shear box. Such a test considered volumetric and void ratio variations with the interface displacement. Its results have shown a sensitive response of the interface behavior with the test conditions, which are closely related to shear zone thickness (fig. 4a). In this context, the spacing between boxes (this spacing should be equal to the thickness of the geotextile plus the maximum soil diameter, in a soil-geotextile-soil type arrangement), the soil layer thickness (greater or equal to 5 times the soil maximum diameter for the bottom layer, and with upper shear box completely full) and the geotextile anchorage conditions (the geotextile should be preferentially fixed at the frontal end of the moving box) are the most important parametric factors for this test.

With the aim of reducing the transversal strain effects on the geotextile during the tests, a system of needles was applied to the geotextile edges. This system consisted of metallic needles uniformly spaced and placed on both sides of the shear box. Special care was taken to minimize displacement friction of the needles with the equipment. Regarding this point, systematic control was done. Figure 4b shows a typical result for the reference needles 15, 30 and 45, which were placed at the front, at the center, and at the back of the textile sample, respectively (displacement of the needles were measured as the average of the values obtained in both box sides) for a given interface which consisted of cohesive soil and geotextile both woven and non-woven. The interpretation of these results allowed to evaluate the zones of greater distortion and the strain distribution throughout the membrane.

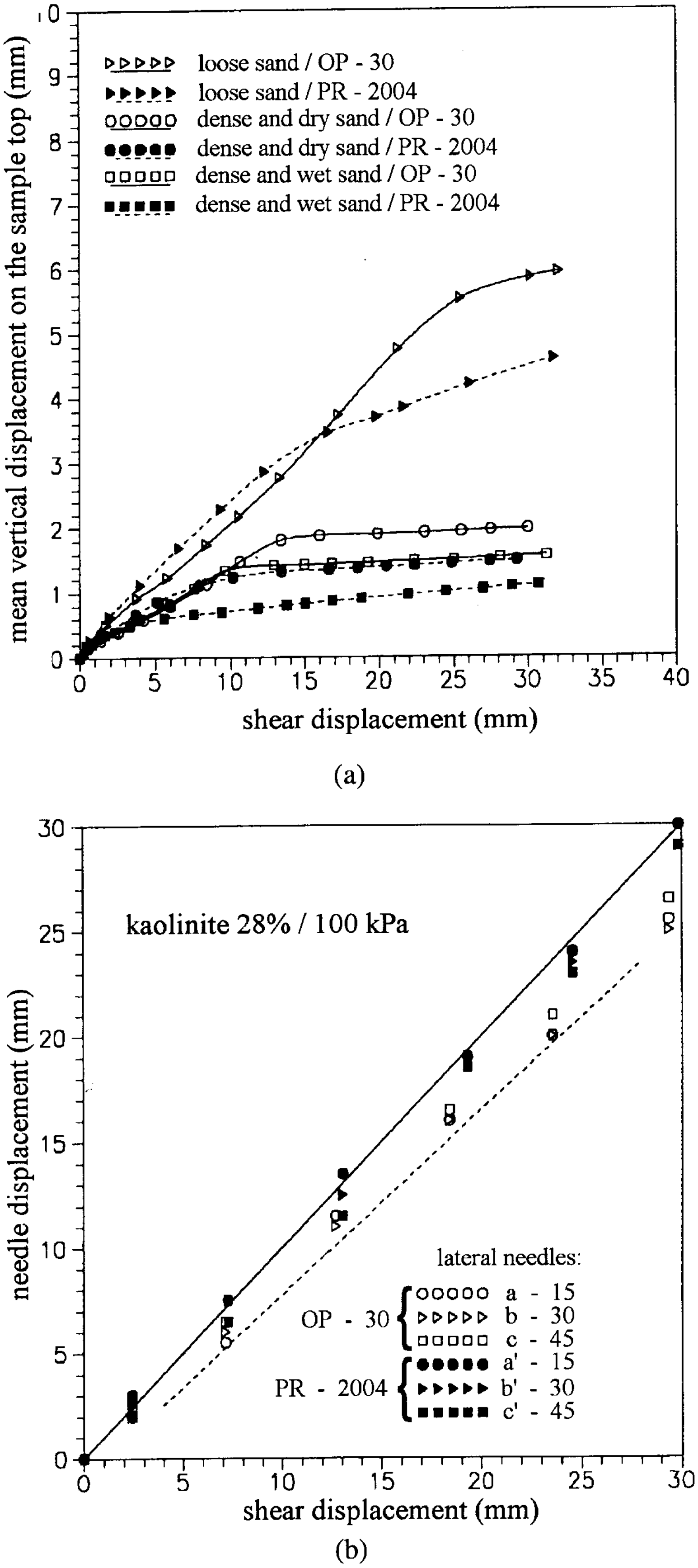


Figure 4 Volumetric variation (a) and movement of the lateral needles (b) with the interface displacements

4. MECHANICAL BEHAVIOR OF GEOTEXTILES UNDER CONFINEMENT.

The confinement action results fundamentally in a process of structural reorganization of the textile fibers with different impacts on mechanical properties of both woven and non-woven geotextiles. In the case of non-woven geotextiles, whose stress-strain behavior is governed by its textile structure, these effects are particularly relevant. Besides they are very often associated to mechanism of soil particle penetration into the geotextile, and reduction of the width contraction of the membrane. These effects result primarily in a substantial increase of the geotextile stiffness with the confining stress, and secondarily, in an increase of the tensile strength, and in a smaller strain of the geotextile at maximun load , in relation to those parameters which refer to non-confined conditions.

The soil granulometry and the particle angularity have secondary effect on the mechanism of soil-geotextile interaction. However, the interface response was highly affected by the characteristics of mass per unit area, thickness, and roughness of the geotextiles tested. These results can be interpreted by the relation between values of confined stiffness under 100 kPa (J_{100}) and stiffness in-isolation (J_0) for sand and pebble geotextile interfaces, for example (Figures 5a and 5b).

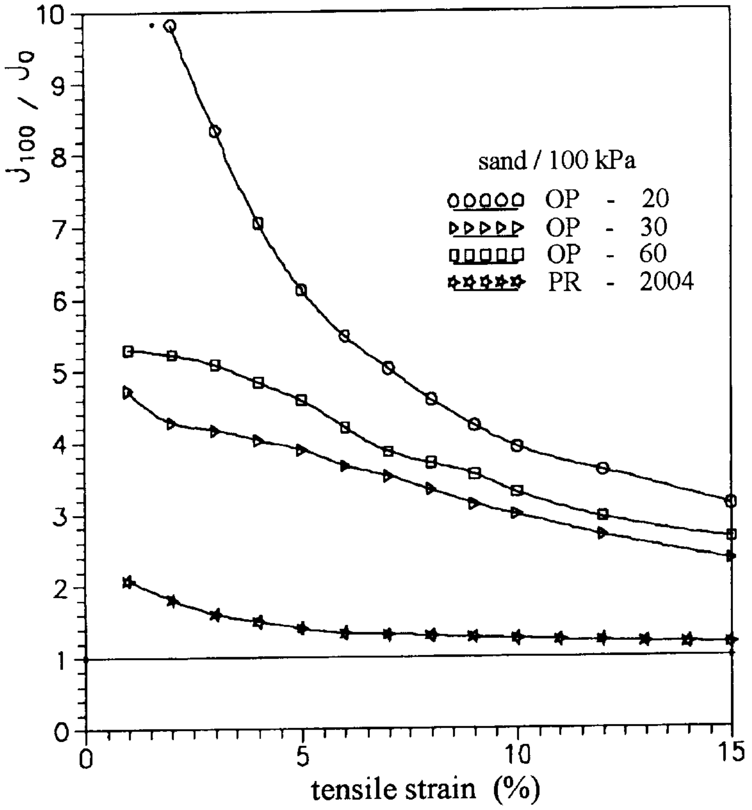


Figure 5a Results of in-soil tensile tests for sand with woven and non-woven geotextiles: confined stiffness x in isolation stiffness relations.

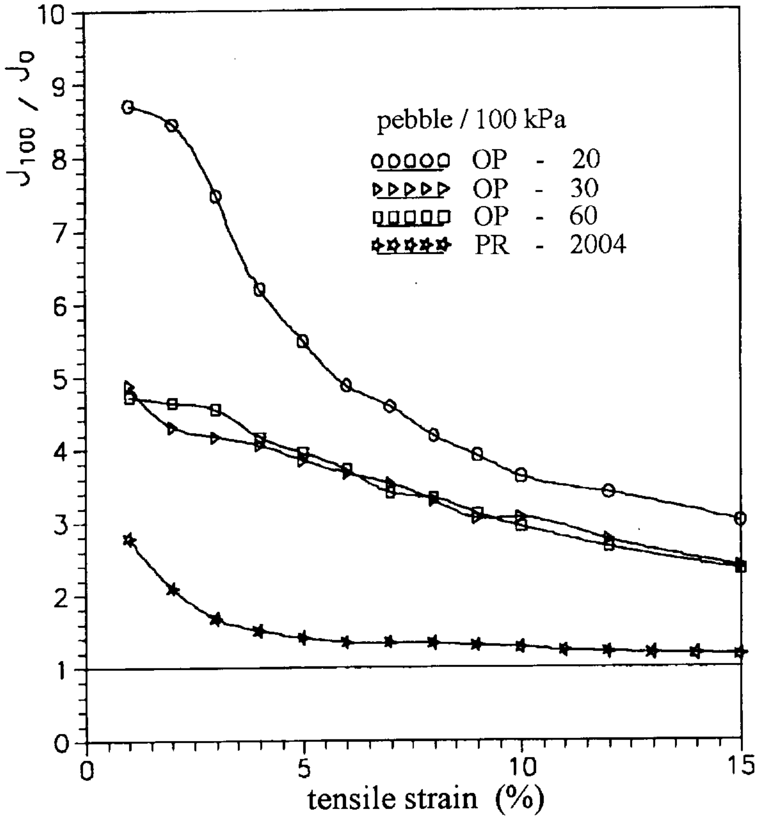
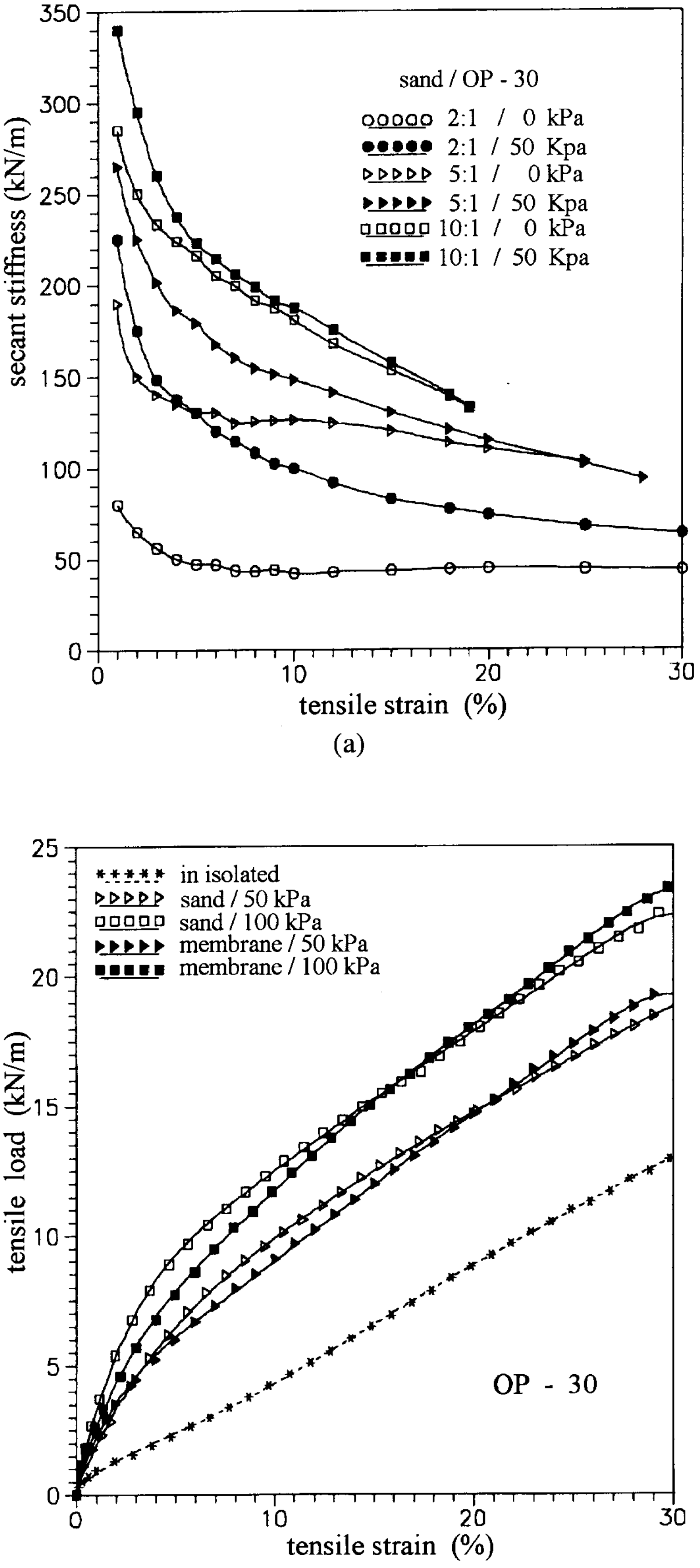


Figure 5b Results of in-soil tensile tests for pebble with woven and non-woven geotextiles: confined stiffness x in isolation stiffness relations.

More substantial increases on stiffnesses were observed for the OP-20 type non-woven geotextile, which were caused by a higher compaction of the original loose matrix. The OP-30 and OP-60 geotextiles presented similar gains of stiffness. On the other hand, for the woven textile PR-2004, the observed relations show limited influence of confinement on its stiffness characteristics. This was due to, in the case of woven geotextile, the fact that its tensile behavior is governed by strength properties of the fibers (being a function, therefore, of intrinsic factors such as the polymer-base nature and the technology used to make the geosynthetic).

Specific series of tests were done with the aim of checking the influence of the sample geometry (width-length relations) and the nature of the confining element on the geotextile response to in-soil tensile stresses. In the first case, the effects were particularly critical in terms of geotextile stiffness characteristics (fig.6a), and were also conditioned by the variation of the position of the rupture surface developed in the inclusion sample. The utilization of a rubber membrane as a alternative confining element, instead of soil (Ling et al., 1992), has shown to be very feasible for sandy soils (fig.6b). However, it is doubtful its generalized application to other soil types.



(a)

(b)

Figure 6 In-soil tensile tests in geotextiles: influence of the sample dimensions (a) and of the nature of the confining element (b)

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