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Dilation-suction effect on the interface shear strength of a geogrid embedded in a sand

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ABSTRACT

The soil-geosynthetic interface resistance, usually obtained by pullout or direct shear tests, is an essential parameter for design analysis. Interface shear strength between soil and geosynthetics depends of particle shape and size, moisture content of soil, type of geosynthetic normal stress acting at the interface. In the case of sandy soils, volumetric changes at interface during shearing has a significantly effect on pullout strength of geosynthetics. In addition, soil suction and dilation developed during shearing of partially saturated soils are strictly related parameters. However, the behavior of geosynthetic-soil interface and its association with dilation and suction is not fully understood. This study consisted of a series of pullout tests performed in order to assess the effect of dilation-suction developed at the interface shear strength of a geogrid embedded in a sand. The experimental program was conducted using an extruded HDPE geogrid reinforcement and a well-graded sand compacted at different water contents. A small-scale pullout apparatus was instrumented to monitor soil suction and vertical displacements during shearing. The results showed that pullout strength of geogrid-sand interface was greater at moisture conditions and normal stresses that conditioned to dilation. In addition, dilation led to suction increases during shearing.

RESUMO

A resistência da interface solo-geossintético, geralmente obtida por ensaios de arrancamento ou cisalhamento direto, é um parâmetro essencial para a análise do projeto, influenciada pelo efeito do formato e tamanho das partículas, do teor de umidade do solo e da tensão confinante. No caso de solos arenosos, a dilatância e sua relação com o tipo de geossintético são fatores que podem influenciar o comportamento da interface. Além disso, sob condições parcialmente saturadas, a sucção e a dilatação do solo estão estritamente relacionadas, embora não totalmente compreendidas. Este estudo é baseado em ensaios de arrancamento realizados com uma geogrelha incorporada em uma areia bem graduada compactada em diferentes condições de umidade. Um equipamento de arrancamento em pequena escala foi instrumentado para monitorar a sucção do solo e os deslocamentos verticais durante o arrancamento. Os resultados mostraram que a dilatação no arrancamento das interfaces areia-geogrelha pode estar associada a mudanças na sucção do solo, bem como o arrancamento pode gerar sobrepressão em condições de inundação.

1. INTRODUCTION

Soil-geosynthetic interaction mechanisms have been recently studied by many authors in view of their importance in the design and performance of geosynthetic-reinforced soil structures. The mechanical behavior of soil-reinforcement interfaces depends on soil physical properties (particle size, mineralogy, density, saturation degree) and geosynthetic properties (type, structure, texture, stiffness and permeability) (Anubhav and Basudhar 2013; Esmaili et al. 2014; Hatami and Esmaili 2015; Khoury et al. 2011; Vangla and Latha 2015; Vangla and Latha Gali 2016; Zhao et al. 2014). As regards the effect of particle size of backfill on the behavior of soil-geosynthetic interface, volumetric change during shearing may be an important factor as additional stresses at the interface can be introduced influencing the interface shear strength. (Afzali-Nejad et al. 2017).

In traditional soil mechanics, sandy soils under shearing reveal compression and dilatancy phenomena depending on the soil density, saturation degree and vertical stress levels. Low levels of confining pressures led to dilation of compacted sands. Similarly, during pullout tests, the soil tends to expand during shearing but affected by the geometry and type o reinforcement. Usually, interface dilation is restricted leading to an increment of confinement stress, which may cause an increasing in frictional resistance and, consequently, in interface resistance (Teixeira et al. 2007). Also, the volumetric change of sandy soils may develop negative (suction) or positive pore water pressures (PWP) depending on moisture and compaction conditions.

This study aims to contribute for the understanding of the behavior of the soil-geogrid interface by the evaluation of dilation-suction effect on the interface shear strength of a geogrid embedded in a sand using a small-scale pullout test. Although this type of apparatus has been reported to be susceptible to border effects, studies have shown that it can be used for comparative and qualitative evaluations (Anubhav and Basudhar 2013; Esmaili et al. 2014; Hatami and Esmaili 2015; Khoury et al. 2011; Portelinha et al. 2018). Differently to most of pullout tests, the proposed pullout apparatus of this research allows measuring vertical displacement as confining stresses are applied.

2. MATERIALS AND METHODS

2.1 Materials

A well-graded clean sand was used as fill material in the pullout tests. A summary of soil properties is shown in Table 1. The water retention curve was obtained by hanging column tests as suggested in ASTM D6836-16. The experimental points were fitted to the Van Genuchten's model. Figure 1 shows the water retention curve of the sand as well as moisture content values (and respective matric suction values) of samples used in pullout tests.

A polypropylene biaxial extruded geogrid (GGE) was used as reinforcement material. General properties are shown in Table 2. The dimensions of the geogrid sample were 11.3 x 22.5 cm with three longitudinal ribs and five transversal ribs embedded in sand.

Table 1. Summary of soil properties.

Properties	Values	Standard specification
Course Sand (%)	40	ASTM D422-63
Medium Sand (%)	50	ASTM D422-63
Fine Sand (%)	9	ASTM D422-63
Fines (%)	1	ASTM D422-63
C_u	2.28	
C_c	1.11	
Unified Soil Classification System (USCS)	SW	
Gs, Specific Gravity	2.65	ASTM D854-14
Liquid Limit (%)	---	ASTM D4318-10e1
Plasticity index (%)	---	ASTM D4318-10e1
$e_{MÁX}$	0.70	NBR 12004
$e_{MÍN}$	0.52	NBR 12051
$\gamma_{d\ MIN}$ (kN/m^2)	15.7	ASTM D698-12e2
$\gamma_{d\ MAX}$ (kN/m^2)	17.1	ASTM D698-12e2
W_{ot} (%)	4.0	ASTM D698-12e2
Friction Angle - $\gamma_{d\ MAX}$ (Optimum moisture)	30.6	ASTM D3080
Cohesion - $\gamma_{d\ MAX}$ (Optimum moisture)	4.7	ASTM D3080
Effective Friction Angle - $\gamma_{d\ MIN}$ (kN/m^2) (Other moisture)	27.1	ASTM D3080
Effective Cohesion - $\gamma_{d\ MIN}$ (kN/m^2) (Other moisture)	5.4	ASTM D3080

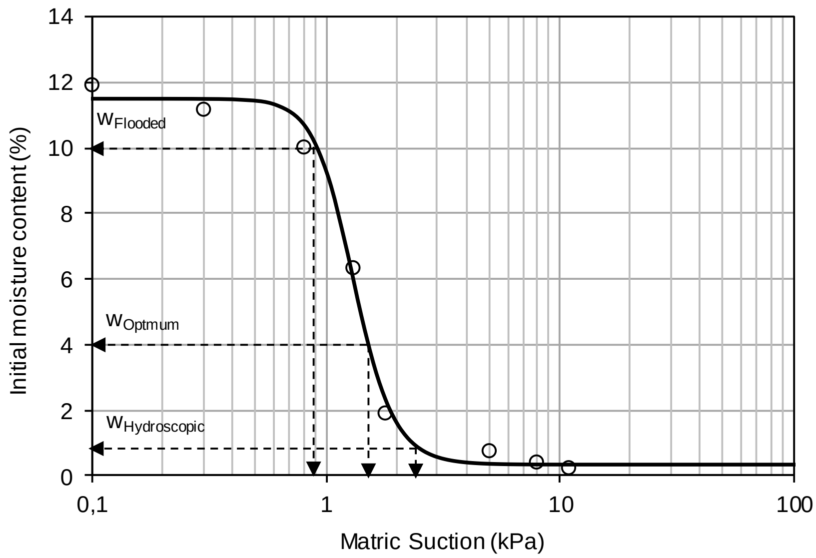


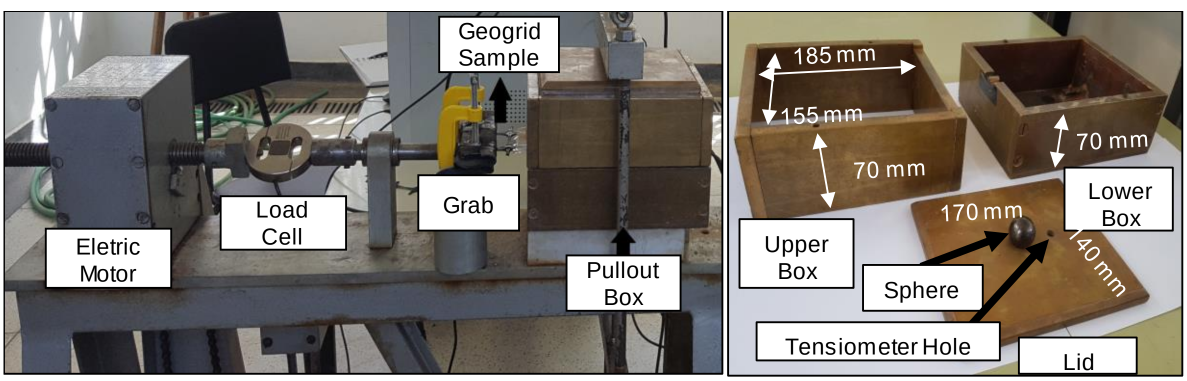
Figure 1. Water retention curve (wetting) of the sand.

Table 2. General characteristics of the geogrid.

Geogrid Properties	Machine Direction	Cross-Machine Direction	Standart
Ultimate tensile strength (kN/m)	58	58	ASTM D6637-11
Tensile strength at 2 % strain (kN/m)	14	14	ASTM D6637-11
Tensile strength at 5 % strain (kN/m)	28	28	ASTM D6637-11
Aperture dimension (mm)	40	40	-
Yarn thickness (mm)	1.5	1.5	-
Yarn width (mm)	4	4	-

2.2 Pullout test apparatus

The small-scale pullout test consisted of a modified conventional direct shear test apparatus (Figure 2a). The adaptation consisted of replacing the direct shear box for a larger steel box composed of upper and lower rigid boxes (Figure 2b). The upper box has an opening in the front wall where the geosynthetic can be pulled out from the box.



a) overview

b) dimensions of the test box

Figure 2. Small pullout tests equipament.

The internal dimensions of the metallic pullout box are: 185 mm long, 155 mm wide and 140 mm high, obtaining an approximate volume of 4014.5 cm^3. The front wall has an opening of 146 mm where the reinforcement is pulled out from the testing box by a clamp attached to one end of geogrid specimen. A rigid metallic lid was placed over the soil surface for vertical stress application. A 7 mm diameter hole was used at the lid to insert the tensiometer for suction monitoring.

2.3 Instruments

The pullout strength was evaluated using an Omega stainless steel “S” type load cell rated at 10 kgf to 10,000 kgf for traction and compression, with a sensitivity of 3 mV / V ± 0.0075. mV / V and a total scale deviation of 0.25 to 0.50 mm. Vertical displacements were monitored using a Linear Variable Differential Transformer (LVDT) digital displacement transducer (± 1.5 to ± 250 mm). The pore water pressures and suction monitored during pullout tests were measured using a UMS type 5T-10 tensiometer with a diameter of 5 mm with range of +100 kPa to -85 kPa and accuracy ± 0.5 kPa.

2.4 Small Pullout Tests

In order to mitigate the attritive edge effects during the tests, two layers of lubricated cellulose paper were used in the testing box. On the front wall, a styrofoam piece was used to reduce the stiffness of the face, as this parameter can affect the test behavior, as observed by Palmeira (2004).

The sand was compacted by sand pluviation technique in 3 layers for each part of the box. After compacting the lower portion of the test box, the geogrid coupled to the test claw was installed. After compacting the upper portion, the tensiometer was introduced and positioned close to the sand-geogrid interface.

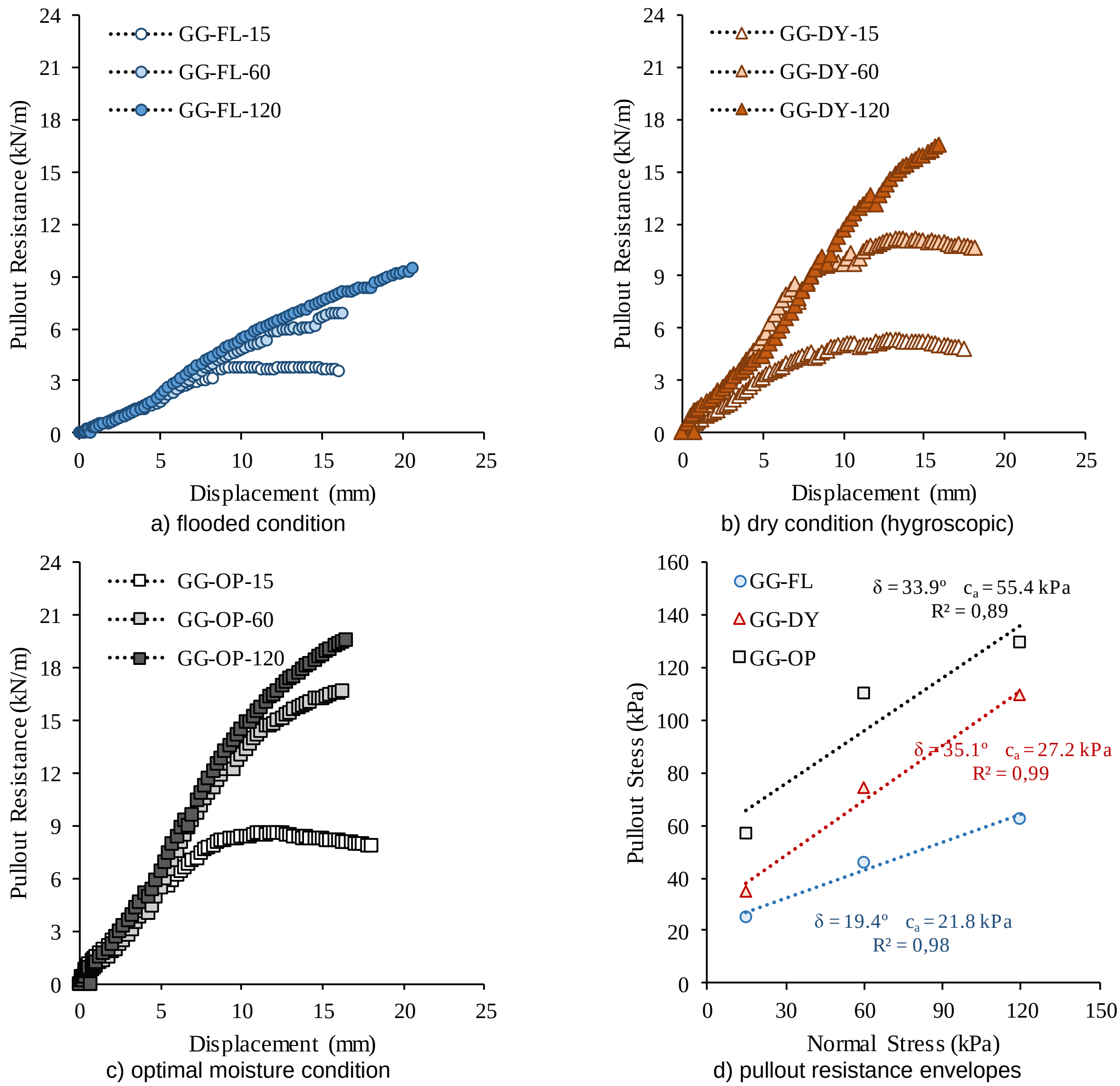
The test setup was set as three test sets for three different moisture conditions: hygroscopic moisture (air-dried), optimum compaction moisture and flooding. The tensions of 15, 60 and 120kPa were used for the confinement of the samples and the speed of 0,5 mm/min was used to guarantee the drainage of the tests (mainly for the flooded condition).

3. RESULTS

Figure 3 presents the results of sand-geogrid interface pullout tests for the different moisture conditions. Results show that the rupture occurred at the interface, with no rupture of the geosynthetic material during the tests. Flooded interfaces (Figure 3a) showed lower pullout resistance values than the others. The presence of water in the flooded interfaces lead to decrease of the soil suction, decrease of the effective normal stress at this interface and its shear resistance.

Figures 3a - 3c also shows that the stress-strain behavior presented resistance behavior without defined peaks, resembling the low compactness conditions for sands. Resistance mobilization was higher for higher stresses, mainly due to the contribution of the passive resistance portion, due to soil entrainment in the geogrid elements perpendicular to the pullout direction.

Considering the soil-geogrid interface area, it was possible to determine the shear stresses for each confining stress level (Figure 3d). As expected, it was observed that the interfaces in the optimal moisture content presented higher resistance parameters than the interfaces in dry and flooded conditions. The interface adherence values obtained in the tests were mainly explained by the passive resistance of the analyzed interfaces.



a) flooded condition

b) dry condition (hygroscopic)

c) optimal moisture condition

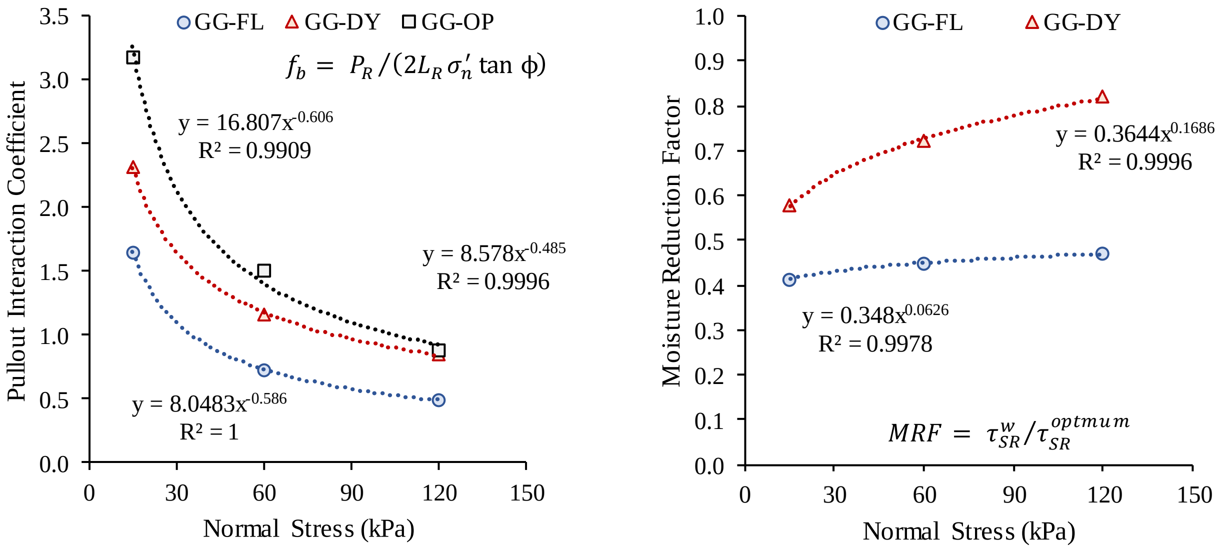
d) pullout resistance envelopes

Figure 4. Pullout test results.

From the rupture information and initial soil parameters, the pullout interaction coefficients obtained in each interface test were determined. It is observed that this coefficient is inversely proportional to the confining normal stress, besides, the relation between these variables is nonlinear decreasing, which results can be identified with good adjustment in power functions (Figure 4a). This fact may be explained by the non-proportional increase in pullout resistance with the increase in confining stress, also due to changes associated with dilatancy and suction.

The optimum moisture condition presented higher pullout interaction coefficient, while the flooded condition presented lower values, about 54% to 58% lower, and the dry condition presented reductions of 17% to 37%. In Figure 4a, the increase of the confining stress presented smaller dispersions for the pullout interaction coefficient, being these values concentrated in the range 0.5 to 1.0. A convergence of the pullout interaction coefficient values for unsaturated conditions is evidenced.

From the pullout resistance envelopes obtained for the different moisture conditions, the concept of Moisture Reduction Factor (MRF) proposed by Esmaili et al.(2014) for fine soil – geotextile interface, has been expanded to the interface of this study and is shown in Figure 4b. The MRF did not present significant variations for the flooded interfaces, while the dry interfaces presented an increase in this factor with increase in normal stresses.



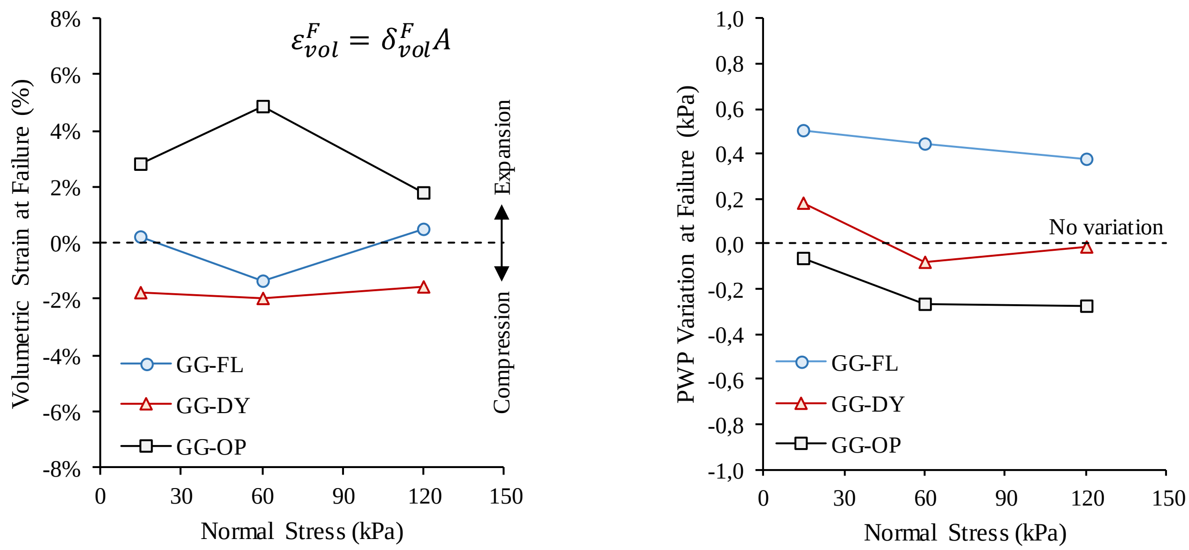
a) pullout interaction coefficient

b) moisture reduction factor

Figure 4. Evaluation parameters of pullout strength.

Considering the vertical displacement occurred at the interface rupture point, the volumetric strain of the sample was determined, and results are presented in Figure 5a. The interfaces with dry soil presented compression behavior, and strains did not change with the increase in normal stresses. The lubrication of the particles facilitated the accommodation and compactness of the interfaces in optimum moisture content, presenting volumetric dilatation and indicating a compact behavior stage. Excessive water in the pores (flooded condition) showed a negligible volumetric deformation at the rupture point.

Using the soil retention curve and the capture of the pore water pressure variation by the tensiometer during the tests, it was possible to verify that the interfaces presented pore water pressure variation little influenced by the confining stresses (Figure 5b). The interfaces in optimum moisture presented a suction gain, possibly correlated to the soil dilation condition. In flooded condition cases, the presence of water annulled the volumetric oscillations of the interfaces, while there was gain of pore water pressures, indicating a possible static liquefaction effect.



a) volumetric strain

b) variation of pore water pressure

Figure 5. Influence of confining stress.

Figure 6 shows the correlations obtained between different variables and the pore water pressures obtained at the interfaces. From dry condition, it was verified that the increase in moisture showed a tendency of volumetric expansion for all levels of confining stresses, with reduction of suction. Due to the low suction levels present in the soil, the quantification of the effect of dilation on this variable was not performed. However, there is was a tendency of increase in suction with the compression of the samples and increase in pore water pressures with soil expansion. These factors also contributed to the interface resistance gain, since the normal tension variations did not present homogeneous pullout stress gains.

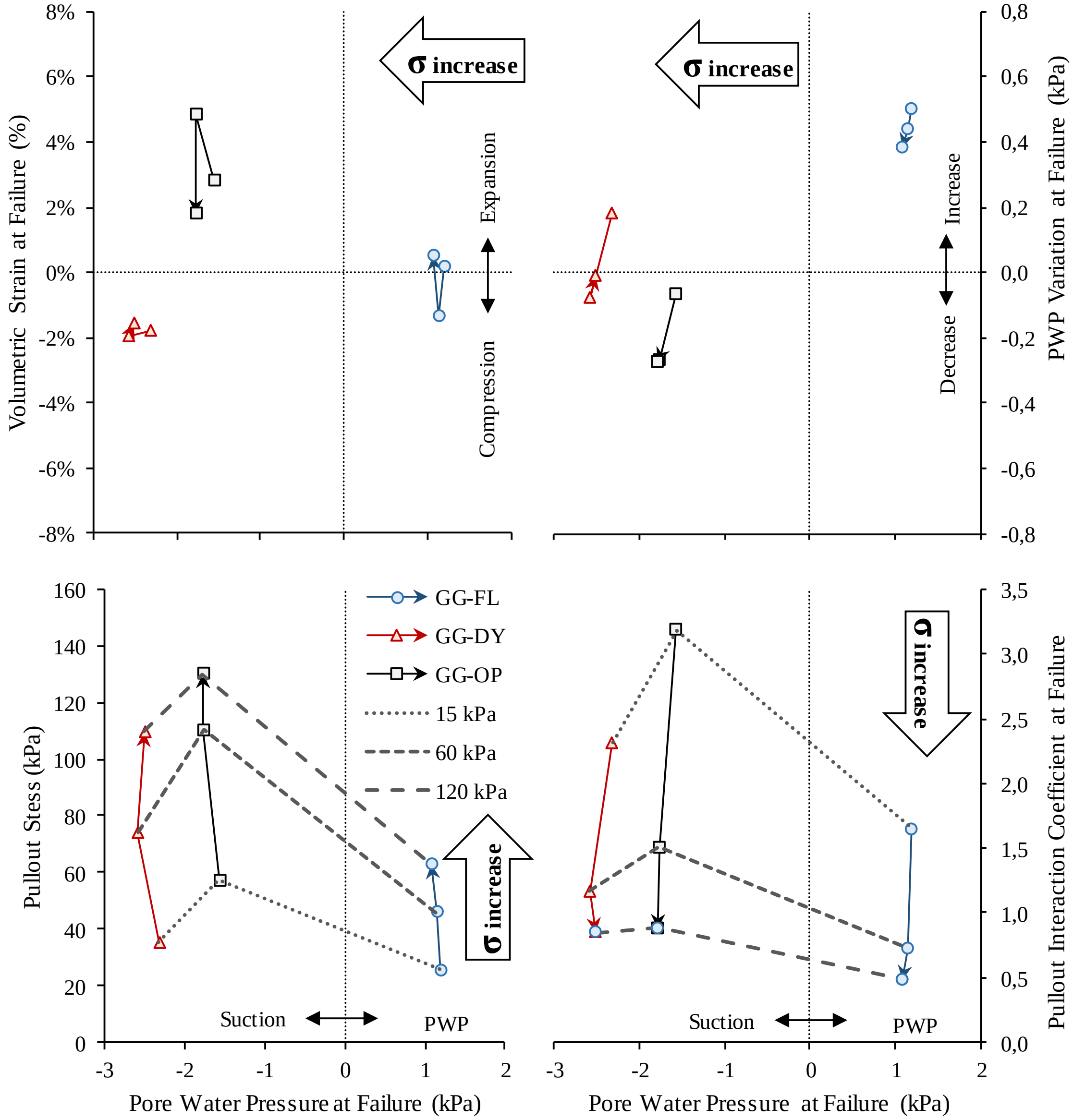


Figure 6. Relationship between pore water pressure and pullout test parameters.

Results demonstrated that pullout interaction coefficients is sensitive to the suction and dilatance effects, which is identified by its the variation for the different interface conditions. As regards the effect of volumetric strain during pullout, it was found that the interaction coefficient decreases when the deformation points tended to zero (arrowhead points), a condition that can be satisfied by long anchor lengths or low tearing forces. The variation of pore water pressure during the tests presented similar magnitude for all levels of initial pore water pressures pressure.

4. FINAL CONSIDERATIONS

From small interface pullout tests, sand-geogrid interface behavior under different moisture conditions were evaluated. From the results, it can be verified that:

- There has been a drastic change in interface resistance by flooding the samples. The suction condition also enabled gains in interface resistance;
- The pullout interaction coefficient showed nonlinear behavior with the confining stress of the tests, presenting convergence region from 0.5 to 1 for high confining stresses;
- The flooded condition did not present MRF alteration with the increase of the confining tension, as well as absence of volumetric variation, besides presenting pore water pressure gain, indicating possible static liquefaction behavior;
- The dry condition showed a considerable gain of resistance with the increase of the confining stress, mainly due to the increase of the attractive interaction between the particles and the geogrid. The volumetric variation was the same for the different tests, as well as the absence of suction variation;
- Although no direct correlation formulations are available, it is possible to identify that the reduction of sand dilatation during pullout was associated with the increase of the suction of the test, while its expansion presented an increase of pore water pressure inside the sample;
- Complementary tests with different moisture levels and interfaces are recommended to enhance these observations.

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6. REFERENCES

ABNT. NBR 12004: Solo - Determinação do índice de vazios máximo de solos não coesivos. Rio de Janeiro, RJ, www.abnt.org.br.

ABNT. NBR 12051: Solo - Determinação do índice de vazios mínimo de solos não coesivos. Rio de Janeiro, RJ, www.abnt.org.br.

Afzali-Nejad, A., Lashkari, A., and Shourijeh, P. T. (2017). “Influence of particle shape on the shear strength and dilation of sand-woven geotextile interfaces.” Geotextiles and Geomembranes, Elsevier Ltd, 45(1), 54–66.

Anubhav, and Basudhar, P. K. (2013). “Interface behavior of woven geotextile with rounded and angular particle sand.” Journal of Materials in Civil Engineering, 25(12), 1970–1974.

ASTM D 422-63. Standard test method for particle-size analysis of soils. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D3080. Direct Shear Test of Soils Under Consolidated Drained Conditions. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D4318-10. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D6637. Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D698-12. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM D854-14. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. ASTM International, West Conshohocken, PA, www.astm.org.

Esmaili, D., Hatami, K., and Miller, G. A. (2014). "Influence of matric suction on geotextile reinforcement-marginal soil interface strength." Geotextiles and Geomembranes, Elsevier Ltd, 42(2), 139–153.

Hatami, K., and Esmaili, D. (2015). "Unsaturated soil-woven geotextile interface strength properties from small-scale pullout and interface tests." Geosynthetics International, 22(2), 161–172.

Khoury, C. N., Miller, G. A., and Hatami, K. (2011). "Unsaturated soil-geotextile interface behavior." Geotextiles and Geomembranes, Elsevier Ltd, 29(1), 17–28.

Palmeira, E. M. (2004). "Bearing force mobilisation in pull-out tests on geogrids." Geotextiles and Geomembranes, 22(6), 481–509.

Portelinha, F. H. M., Pereira, V. R. G., and Correia, N. S. (2018). "Small-scale pullout test of a geogrid-reinforced unsaturated soil with suction monitoring." Geotechnical Testing Journal, 41(4), 787–804.

Teixeira, S. H. C., Bueno, B. S., and Zornberg, J. G. (2007). "Pullout Resistance of Individual Longitudinal and Transverse Geogrid Ribs." Journal of Geotechnical and Geoenvironmental Engineering, 133(1), 37–50.

Vangla, P., and Latha, G. M. (2015). "Influence of Particle Size on the Friction and Interfacial Shear Strength of Sands of Similar Morphology." International Journal of Geosynthetics and Ground Engineering, 1(1).

Vangla, P., and Latha Gali, M. (2016). "Effect of particle size of sand and surface asperities of reinforcement on their interface shear behaviour." Geotextiles and Geomembranes, Elsevier Ltd, 44(3), 254–268.

Zhao, Y. R., Xie, Q., Wang, G. L., Zhang, Y. J., Zhang, Y. X., and Su, W. (2014). "A study of shear strength properties of municipal solid waste in Chongqing landfill, China." Environmental Science and Pollution Research, 21(22), 12605–12615.