Experimental evaluation of the pullout resistance of polymeric strips within uniform sand and lateritic silty soil

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ABSTRACT: Reinforced earth is as a construction system of retaining walls where tensile elements strengthen the soil, increasing the global shear resistance. Galvanized metal or polymeric strips may be used as reinforcements. The use of polymeric strips, also called geostrips, has increased in recent years because of their technical and economic advantages. Additionally, the type of selected soil as backfill material in reinforced earth is also preponderant for the internal stability of the structure. Usually, it is recommended the use of granular materials, such as sands. Nowadays, many works can be found in literature about pull-out tests of these kinds of reinforcements, however there is a lack of information of studies on the interface resistance of reinforced lateritic soils, typical in tropical regions. The present research has studied the pullout resistance of polymeric strips in two different kinds of soils by means of large scaled laboratory pullout tests, aiming to study different soil-reinforcement interfaces. Based on the results, it was possible to quantify the pullout resistance of the polymeric strips, allowing the delimitation of design parameters.

Keywords: Reinforced earth, metallic strips, polymeric strips, interface shear strength resistance.

1 INTRODUCTION

Understanding soil-reinforcement interface resistance mechanisms is important for designing mechanically stabilized earth walls, such as reinforced earth structures. Basically, this kind of structure consists of a compacted backfill with adequate geotechnical properties, flexible reinforcements horizontally placed and a flexible concrete face, where the reinforcements are fixed (ABNT 2016). The reinforcements are linear elements whose performance depends on the soil-strip adherence. In this context, geotechnical properties of the backfill materials are important to mobilized satisfatory tensile forces, being recommended the use of good quality soils, like coarse sands.

Although the use of granular soils is desirable in geosynthetic reinforced soil walls, finding deposits of materials with adequate properties close to the construction site can be difficult and expensive. For this reason, many works can be found in the literature regarding the use of unconventional construction materials, aiming at sustainability and economy. Some examples can be citted, such as the use of soil-rock mistures (Yang *et al.* 2014), the use of fine-grained tropical soils (Riccio *et al.* 2014; Tupa 1994), the use of copper slag (Prasad & Ramana 2016) and the use of recycled construction waste (Santos *et al*., 2014; Vieira *et al*. 2016) as backfill in reinforced walls. However, a few works have shown results with the use of lateritic soils, typical in tropical countries, like Brazil. Besides that, many researches can be found in the literature on the use of metallic strips in reinforced walls, but just a few investigations bring informations on tests with synthetic strips, specially when used in lateritic soils.

Weldu et al. (2015) performed a series of laboratory tests to study the pullout resistance of mechanically stabilized earth walls considering the use of steel strip reinforcement in uniform aggregates with uniformity coefficients (C_U) ranging from 1.4 to 14. The authors concluded that the AASHTO (2012) default F* values were conservative when compared with the test data, even for aggregates with Cu < 4 (uniform aggregate.

An experimental analysis about shear tests and pullout tests by means of large scale laboratory equipment can be found in Palmeira (1987) and Palmeira (2009). The research presented an investigation into soil-reinforcement interaction, investigating scale and other factors affecting test results. Among other conclusions, the authors highlights that pullout test results can be severely affected by boundary conditions, in particular by the friction on the front wall of the box. Other pullout tests in geogrids were presented by Teixeira (2003), Moraci & Recalcati (2006), Teixeira et al. (2007), Alagiyawanna *et al.* (2001) and Abdi & Arjomand (2011).

The present work presents a study about the pullout resistance of two different kinds of polymeric strips buried in a uniform sand and in a lateritic silty soil, characteristic of the city of Brasilia, Brazil. The pullout tests were performed in a large-scale equipament, which was adapted for linear reinforcements. The main objective was to evaluate soil-geostrip interface resistance in materials with distintive geotechnical properties and to compare the results with standardized regulations. It was also possible to quantify the influence of the high adherence geostrips in relation to conventional strips.

1.1 *Guidelines for Pullout Resistance Determination*

Standard D6706-01 (ASTM 2013) presents the test method for measuring geosynthetic pullout resistance in soil using a laboratory pullout box. According to this source, the pullout resistance per unit length ($T_{máx}$) is determined by:

$$T_{m?} = \frac{F_{m?}}{W_g} \tag{1}$$

where $F_{máx}$ = pullout force and W_g = width of the geosynthetic.

According to AASHTO (2012), the pullout friction factor (F*) for strip reinforcements is given by:

$$F^* = \frac{T_{m?}}{\phi * \alpha * \sigma_v * C * L_e} \tag{2}$$

where $T_{máx}$ = pullout resistance, Φ = resistance factor for reinforcement pullout (0.90 for pullout resistance of tensile reinforcement considering service limit state and 1.00 for extreme event limit state), α = scale effect correction factor (1 for steel reinforcements and geostrips), σ_n = vertical overbuden stress at the reinforcement level, C = overall reinforcement surface area geometry factor (2 for strips) and L_e = length of reinforcement in the resisting zone.

According to AASHTO (2012), for standard backfill materials (exception of uniform sands, with coefficient of uniformity C_u=$D_{60}/D_{10} < 4$), in the absence of test data, it is acceptable to use conservative default values for F*. For smooth steel strips, F* can be adopted as 0.4. For ribbed steel strips, the following equations must be considered:

$$F^* = \text{tg}\,\phi_f \qquad \text{for } z \geq 6 \tag{3}$$

$$F^* = (1.2 + \log\, Cu) * \left(1 - \frac{z}{6}\right) + tg\,\phi_f * \left(\frac{z}{6}\right) \qquad \text{for } 0 < z < 6 \tag{4}$$

where z = depth below top of wall and $ø_f$ = angle of internal friction of the backfill..

Brazilian standard NBR 19286 (ABNT 2016) also suggests the use of Equations 3 and 4 for F* prediction for metallic strips in the abscense of experimental pullout tests with granular materials under certain conditions. The same regulation recommends to consider F*=tg ø when dealing with fine-grained soils (D_{20} < 0,015 mm ≤ D_{40}, with internal friction angle ≥ 25º).

2 MATERIALS

The characterization tests carried out on th soils (sand and silt) used in this research programame consisted of particle size distribution (ASTM C136/C136M-14, 2014a) and specific gravity (ASTM D854-14, 2014b) for both materials and Atterberg Limits (ASTM D4318-17, 2017a), Proctor test (ASTM D698-12e2, 2012) for the lateritic silty soil and maximum and minimum densities (ASTM D4253-16 and ASTM D425416, 2016a and 2016b, respectively) for the uniform sand. After those tests, the soils were classified according to Unified Soil Classification System (ASTM D2487-11, 2011a) as SP (poorly graded sand) and ML (Inorganic silt). The grain size determination of the fine fraction of the lateritic silty soil was obtained both with and without the use of dispersing agent (ASTM D7928-17, 2017b, Brazilian standard NBR 13602, ABNT 1996), once the grain size distribution curve of this material is highly influenced by the presence of the dispersing agent (Guimarães 2002).

Figure 1 presents the particle size distribution curves and Table 1 presents the main geotechnical properties of the soils tested, as well as some properties adopted for the pullout tests (relative density of the sand and degree of compaction of the silty soil).

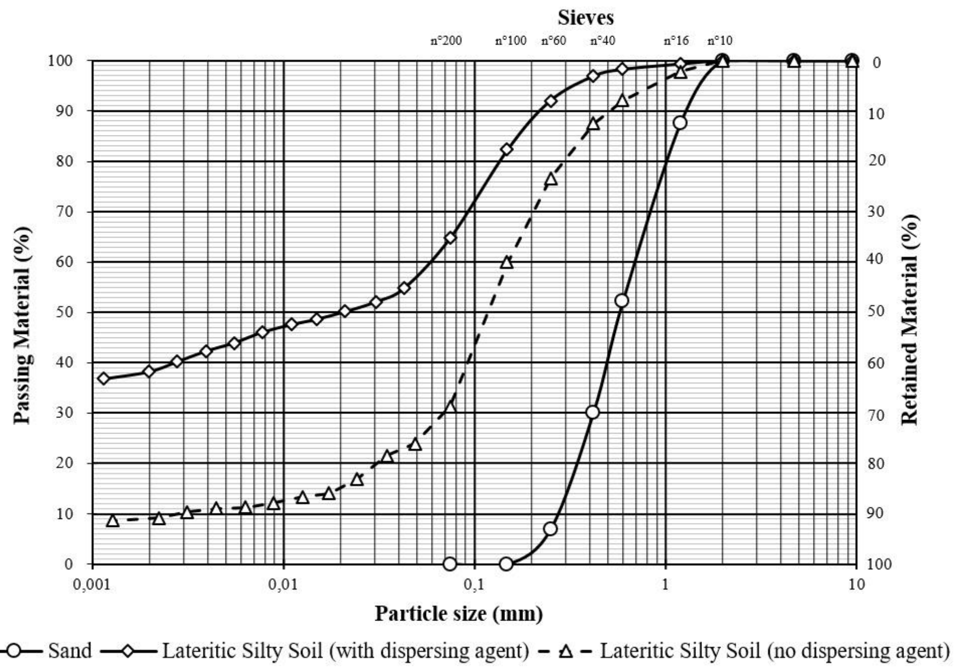

Figure 1. Particle size distribution curves.

Table 1. Geotechnical properties of the materials.

Parameter	Uniform Sand	Lateritic Silty Soil	Unit
Unified soil classification	SP	ML	-
Specific gravity of solids	2.64	2.67	g/cm^3
Liquid limit (w_L)	-	39	%
Plastic limit (w_P)	-	28	%
Plasticity index (PI)	-	11	%
Maximum dry unit weight (Proctor test)	-	2.60	g/cm^3
Optimum moisture content (Proctor test)	-	22	%
Degree of compaction	-	95-100	%
Void ratio of soil in densest condition (e_{min})	0.58	-	-
Void ratio of soil in loosest condition (e_{max})	0.83	-	-
Relative density (D_R)	95	-	%
$C_U=D_{60}/D_{10}$	3	>10	-
$C_C=(D_{30})^2/(D_{10*}D_{60})$	1	<1	-

3 LABORATORY TESTING

Palmeira (1996) designed and constructed a full-scale pullout box, which is composed of steel bars and beams, to perform pullout tests on geogrids. This pullout box is 570 mm high, 900 mm wide and 1450 mm long and was adapted to perform pullout tests in linear reinforcements, such as geosynthetic and metallic strips (Figure 2 – A). The equipament has the following components: box reaction frame, normal stress loading device composed of a water bag, compressed air system and air-water interface system and pullout force loading device, constituted by a hydraulic cilinder, a load cell and a geosynthetic campling system.

The instrumentation of the tests consisted of two displacement transducers with maximum 150 mm stroke, 50 kN capacity load cell (Figure 2 – B) and total stress cells. To reduce side wall friction as much as possible high density polyethylene (HDPE) membranes covered the internal surfaces of the pullout box and a lubricant was spread on the sidewalls, as recommended by ASTM D6706-01. The anchored length of the strips was equal to 1225 mm and the polymeric strips were pulled-out in pairs, one parallel to the other and separated by 50 mm, as shown in Figure 2 – C. This arrangement results in a friction improvement, probably related to an arching effect and a soil dilatancy which are created between the two strips and thus increases the stress area around the inclusions (Abdelouhab *et al*. 2010).

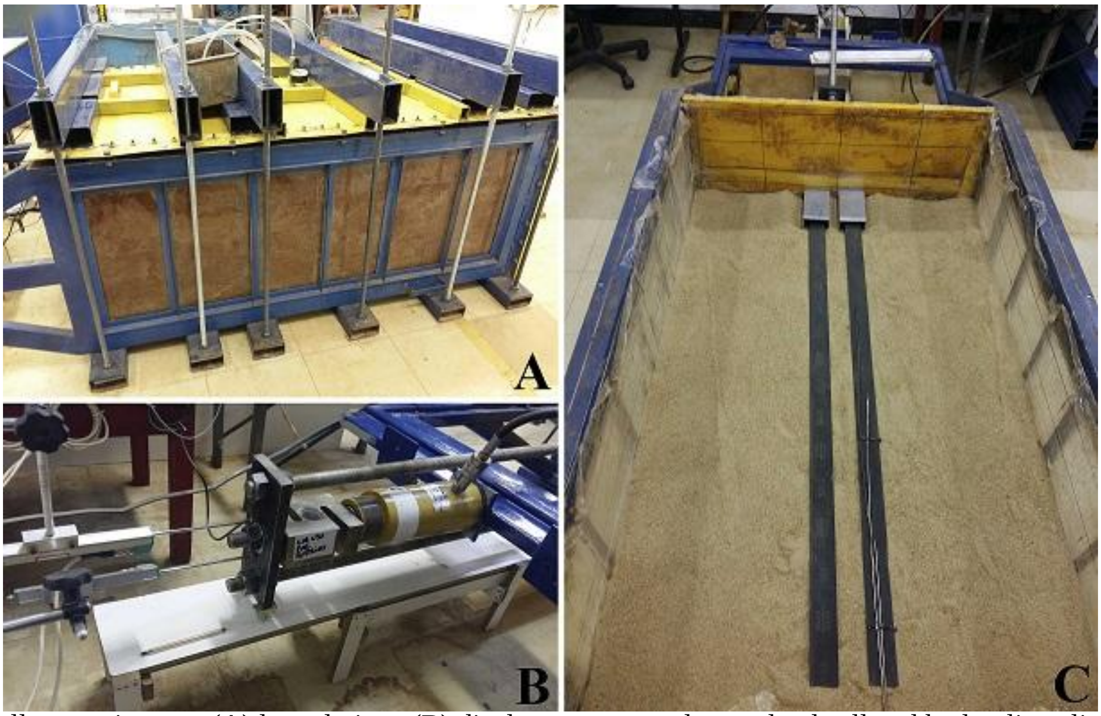

Figure 2. Pullout equipment: (A) lateral view, (B) displacement transducers, load cell and hydraulic cylinder, and (C) conventional synthetic straps within uniform sand.

Fine soil compaction was achieved by means of a hand compaction hammer with a circular base and diameter of 25 cm designed for this research, to obtain the conditions listed in Table 1.

The uniform sand was prepared using the sand rain technique (Pierozan 2016). This method is described by a series of authors (Rad & Tumay 1987, Lo Prest *et al.* 1992 and Brandon *et al.* 2001). Additional compaction with the hand hammer was necessary to achieve the required density (Table 1).The pullout tests were performed with overburden vertical stresses on the strip level equal to 12.5 kPa, 25 kPa and 50 kPa, which included the pressure due to soil weight plus the surcharge on the surface. The reinforcements were tested with uniform sand (conventional and high adherence synthetic strips) and lateritic silty soil (high adherence synthetic strip), resulting in 9 pullout tests.

4 RESULTS

The results from pullout tests with uniform sand and lateritic silty soil are presented in Figure 3 and the maximum pullout resistances ($T_{máx}$) and respective pullout friction factors (F*) are shown in Figure 4.

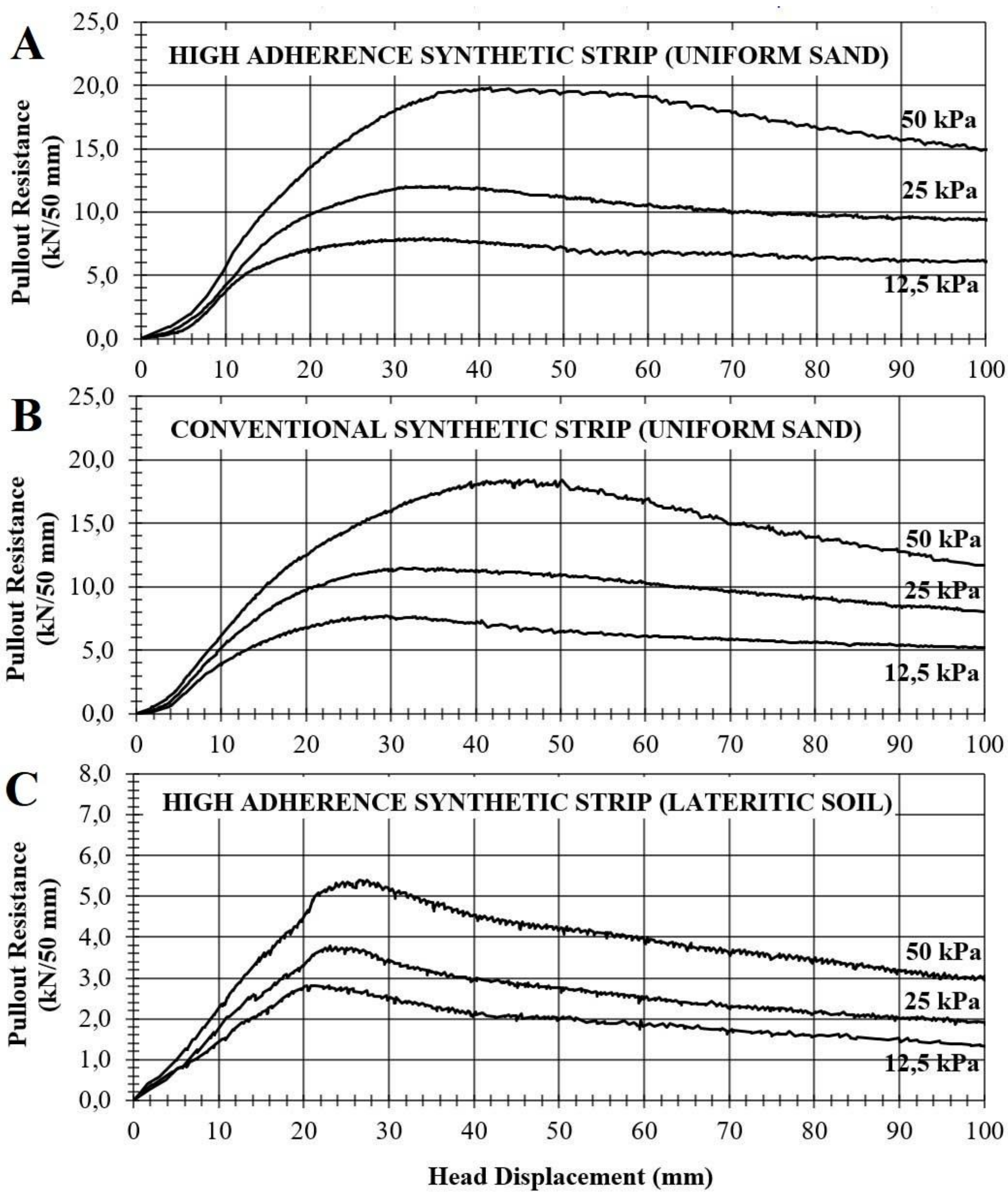

Figure 3. Pullout tests with uniform uniform sand and lateritic silty soil.

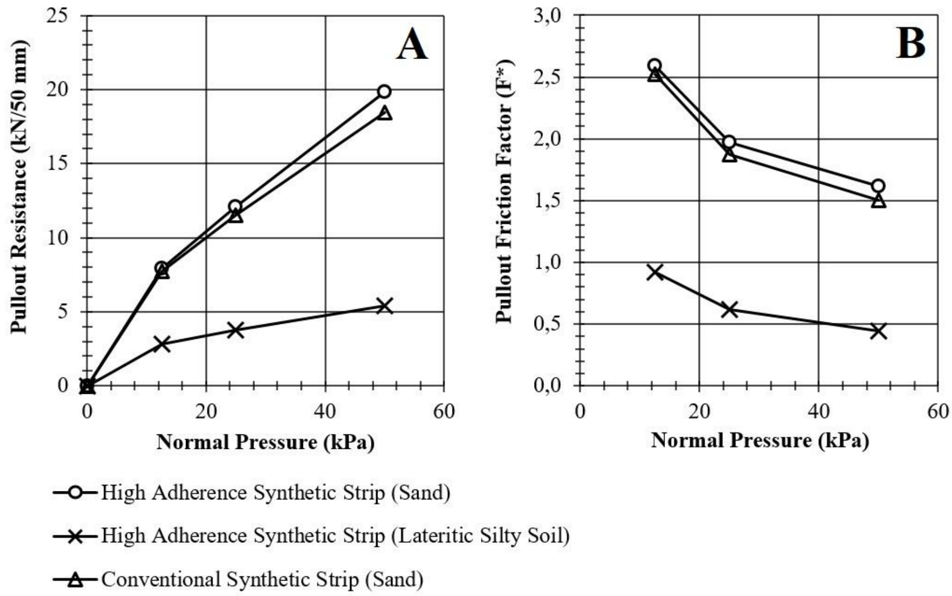

Figure 4. Maximum pullout resistances ($T_{máx}$) and pullout friction factors (F*) from laboratory tests.

Figure 4 shows that the pullout friction factors (F*) obtained were greater than the values recommended by international standards (AASHTO 2012, ABNT 2016), even when considering the lateritic silty soil. This was expected, once standards are conservative and aim at approaching a broad range of situations.

Both the conventional and the high adherence synthetic strips presented better performance when tested in the uniform sand, once this material gather better geotechnical properties for mechanically stabilized earth walls. The pullout friction factors (F*) for the high adherence synthetic strips were slightly greater than that obtained for the conventional synthetic strips (3%, 5% and 8% for normal stresses equal to 12,5 kPa, 25 kPa and 50 kPa, respectively). However, in some cases this level of difference may not justify the use of a more expensive reinforcement material and this must be considered in design.

The lateritic silty yielded to lower pullout friction factors (0.92, 0.61 and 0.44 for normal stresses equal to 12.5 kPa, 25 kPa and 50 kPa, respectively, and for high adherence synthetic strips. These values are close to AASHTO (2012) conservative default values recommended for smooth steel strips ($F^* = tg\ \phi_t = tg\ 33^\circ = 0.65$).

5 CONCLUSIONS

This paper presented a research programme on pullout resistance of conventional synthetic strips and high adherence synthetic strips buried in a uniform sand and in a lateritic silty soil. The latter is a typical soil found in tropical regions. A large-scale equipment was used in the labororatory tests, as well as other auxiliary equipment. The tests allowed to improve the understanding on the soil-reinforcement interaction mechanisms in geostrips and validated the equipment and methodology employed. The use of uniform sand resulted in large interaction factors, greater than the values recommended by current standards. On the other hand, lower interaction factors were obtained in the tests with the fine-grained lateritic soil, but still close to the conservative default values recommended by AASHTO (2012). Further research is in progress to improve the understanding on the interaction between geostrips and fine-grained soils.

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