Evaluation of load-settlement behavior of a Polyethylene Terephthalate (PET) fibers reinforced sand under plate load tests

Évaluation de la performance charge-contraintes de sable renforcé avec des fibres de Polyéthylène Téréphtalate (PET) soumis à des tests de plaque

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ABSTRACT: This study aims to demonstrate that fibers originating from the PET recycling can be a good alternative if used as reinforcement of soils submitted to different load levels. The fibers used are from the textile industry, 100% made from waste polyethylene terephthalate, known as PET, an inert material and harmful to the environment, with a long decomposition time and potential to cause serious environmental problems. For this experimental program, tests were performed to evaluate the physical characteristics and the mechanical behavior of a poorly graded sand reinforced with the addition of PET fibers with a diameter of 0.0098 mm and length of 38 mm, randomly distributed in the soil mass and a PET fiber content of 0,5% in relation to the soil's dry weight. Slopes simulation tests were performed in a reduced model to analyze the load-settlement behavior of the composite and the change that occur in the slope failure. It was observed that the reinforced sand with PET fibers had a greater bearing capacity and a reduction of the settlements if compared with non-reinforced soil. The results were satisfactory, highlighting the positive use of PET fibers in construction where the local soil isn't adequate and its reinforcement possible giving a nobler end to this material.

RÉSUMÉ:Cette étude vise à démontrer que les fibres dérivées de matériau PET recyclés peuvent être une bonne alternative si elles sont utilisées en tant que renfort des sols soumis à différents niveaux de charge. Les fibres utilisées dans l'étude proviennent de l'industrie du textile, 100% fabriquées à partir de déchets de polyéthylène téréphtalate, connu sous le nom de PET, un matériau inerte et nuisible à l'environnement, ayant une longue période de déclin qui pourrait causer de graves problèmes environnementaux. Pour les travaux expérimentaux de ce programme, les essais ont été effectués pour évaluer les caractéristiques physiques et le comportement mécanique d'un sable mal classé amélioré par l'addition de fibres de PET réparties de façon aléatoire dans la masse du sol, avec un diamètre de 0.0098 mm et une longueur de 38 mm, à 0,5% en poids de sol sec. Des essais de simulation des pentes ont été dans un modèle physique réduit afin d'analyser le comportement de la charge-décharge du composé.Il a été observé que le sable renforcé avec des fibres de PET ont une plus grande capacité de support en plus de la réduction des repaires par rapport au sol non renforcé. Les résultats ont été satisfaisants, ce qui souligne l'utilisation positive de la fibre PET dans des constructions où le sol local ne suffit pas, mais où le renforcement de celui-ci est possible et de donner une fin plus noble à ce matériau.

KEYWORDS: PET fibers; reinforced soils; plate load tests; slope simulation tests; reduced physical model.

1 INTRODUCTION

Previously experimental results show that the addition of fibers into soils can have a noticeable reinforcing effect (e.g. Gray and Ohashi 1983, Freitag 1986, Gray and Maher 1989, Maher and Ho 1993, 1994, Nataraj et al. 1996, Consoli et al. 1998, 2002, 2003, 2004, 2009, Zornberg 2002, Tang et al. 2006, Lirer et al. 2012).

The soil fiber reinforcement is an ancient technique (Van Impe 1989) and consist in insert and mix one material in another one to improve their properties. In other words, improve the soil means improve the geotechnical characteristics of soils in works where the local soil is not adequate and the strengthening of the same feasible. The choice of the use of fibers as reinforcement material was taken because they contribute more effectively in the soil resistance in the state after cracking, improving the capacity of energy absorption of the soil-fiber composite. This occurs because the required deformation to cause cracks in the soil matrix is well below the stretching of the fibers (Taylor 1994; Illston 1994; Hannant 1994).

So, this study aims to demonstrate, through slope simulations by plate tests on a reduced physical model, that using PET fibers with a diameter of 0.0098 mm and 38 mm of length and 0.5 % by dry soil weight affect positively the load-settlement behavior and the soil's type rupture. This can be a good alternative when used as a soil reinforcement aimed to apply the reinforced soil as a base shallow foundations, embankments and layers of landfills and embankments on soft soils, for example, eliminating current problems of waste disposal in dumps, landfills and even directly in nature.

2 EXPERIMENTAL PROGRAM

2 .1 *Materials*

2.1.1 *Sand*

The sand used in this study comes from the region of Porto das Caixas, located in Itaboraí, state of Rio de Janeiro. The soil is classified as a medium, uniform, poorly graded (SP) sand and with specific gravity of the solids are 2.65. According to the sieve analysis, the values found for the effective diameter was 0.24 mm and the uniformity coefficient and curvature were respectively 2.9 and 1.0. The maximum and minimum void ratios found were 0.93 and 0.67, respectively.

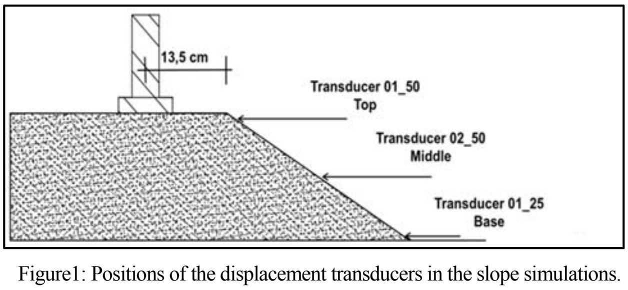

Figure1: Positions of the displacement transducers in the slope simulations.

2.1.2 *Fibers*

As reinforcing material, were used in this study polymeric fibers obtained from recycled materials of Ethylene Terephthalate, commonly known as PET, with a diameter of 0,0098 mm and a length of 38 mm with a specific density of 1.27, a tensile strength of 81 MPa, elastic modulus of 2.8 GPa and elongation at break of 70%.

2 .2 *Sample Preparation*

After air drying, the sand was laid in plastic bags, preventing changes in soil moisture, until the moment it was used in the preparation of the tests. For the sand-fiber composite, the moisture content was set to 10% and dry unit weight of 14.4 kN/m^3 (equivalent to a relative density of 50%).The PET fiber content was0.5% in relation to the dry weight of the soil. The relative density of 50% was chosen because it has a better workability of soil and fiber.

2 .3 *Slope Simulation Tests*

Previously, undrained consolidated triaxial tests were realized on both non-reinforced and reinforced sand with PET fibers to determine how the addition of PET fibers can influence in the strength parameters of the pure soil. It was noted that the addition of fibers can improve the resistance parameters as the cohesion intercept and the friction angle, defined by the Mohr-Coulomb criteria. Table 1 presents a summary of the strength parameters found for a pure sand and composite sand-PET fibers.

Table1: Strength parameters for pure sand and composite sand-PET fiber.

Material	c' (kPa)	ø' (º)
Sand	0	32
Composite sand-PET fiber	22,5	44,4

The purpose of doing the slope simulation testswas structured to analyze how the PET fibers used as reinforcement influence not only the strength parameters but also its effect in the load-settlement behavior of the sand and how it changes the rupture of the slope because of a load increase. It was built a reduce model and the tests were carried out in the Structure and Material Laboratory ate Pontifical Catholic University of Rio de Janeiro. The box was sized according to the criteria of the bulb pressure created (Terzaghi & Peck 1967) only represents the soil characteristics up to two diameters below the plate. The box dimensions were 80 cm long x 60 cm wide x 45 cm thick. The thicknesses of the wooden plates and acrylic were 30 mm and 20 mm, respectively. To avoid problems of buckling walls, it was added a lateral compound of steel section of 2.54 cm, ensuring a better rigidity to the box when applying load. A circular and rigid plate with 10 cm diameter and 2.54 cm thick was used. The plate was attached to a loading system, a universal frame with application of load up to 100 kN and with a data acquisition system for both the load to be applied as for the plate to be engaged in the loading cell. To measure the horizontal displacements created in the slope during load application, three displacement transducers, calibrated previously, were used, two with stroke of 50 mm and one with stroke of 25 mm. Each transducer was placed at a reference point on the slope: on the top, in the middle and in the bottom of the slope.

Figure 1 shows the positions of the displacement transducers.The plate was located at a distance of 13.5 cm from the edge of the slope with the purpose of simulating a case where the loading applied was more critic.

3 RESULTS AND ANALYSIS

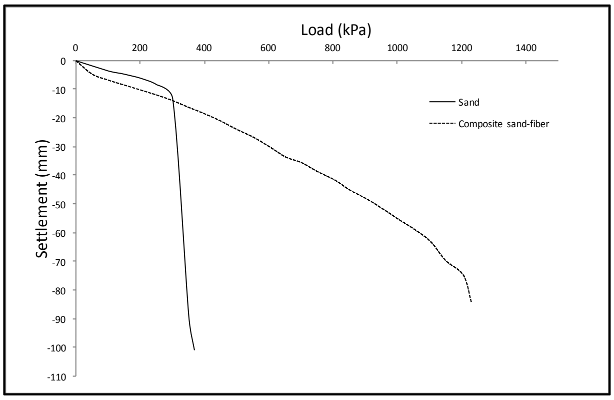

Figure 2: Load-settlement behavior of the sand and sand-fiber composite.

Figure 2 illustrates the results of slope simulation tests conducted on non-reinforced and fiber-reinforced homogeneous samples of sand (0.5% fiber by weight, 38 mm in length and 0.0098 mm thick) under a load velocity of 0.2 kN/s.

The maximum load registered in the plate test for the sand was 367.97 kPa with a measured settlement of 101.05 mm. For the composite, it was recorded a maximum load of 1229.31 kPa and a measured settlement of 84,25 mm. The tests were conducted until the load limit of the system used.

It could be noted that the sand has a smaller displacement than the composite until 300 kPa. That may be caused due to the high volume that the PET fibers provide to the composite, having a higher void ratio. The relative density of 50% used in the test may also cause a loss of initial stiffness.After this stress of 300 kPa, it is visible the change in behavior of the load-settlement curve, that represents the moment in which the fiber begins to act. So, after reaching the rupture stress the sand-fiber composite still withstands the stresses acting.

It can be said that, at the beginning of the test, who resists the initial stress is the sand matrix and for not supporting more active tension and entering a post cracking state, the fibers are mobilized and begin to work as reinforcement.

Analyzing the obtained data, it can be noted that the PET fibers used in the mixture decreases the settlement when compared to the sand submitted to higher stresses. After the sand reaches the rupture, the sand-fiber composite also resists the stresses acting, always with increasing resistance.The decrease in the measured settlement was up to 80 % when compared to the sand.

It is possible to define that the sand suffers from a case of localized rupture, where a wedge is formed under the foundation and there is a notable tendency of lifting the soil that rounds the structure. The soil-fiber composite, experiences a rupture by puncturing, where the vertical movement of the foundation is accompanied by the compression of the soil immediately below, and the soil around practically does not participate in the process.

An explanation for the change of rupture can be linked to the way the grains of sand connect to the fibers, creating a certain apparent cohesion to the ground, producing an increase in resistance to pure soil displacement. Thus, the applied stress that was transmitted directly to the sand, can be dissipated and transmitted through the mass of the sand-fiber composite, preventing the localized rupture.

Figure 3 shows the data of the displacement transducers arranged on the surface of the slope, relative to the horizontal displacements.

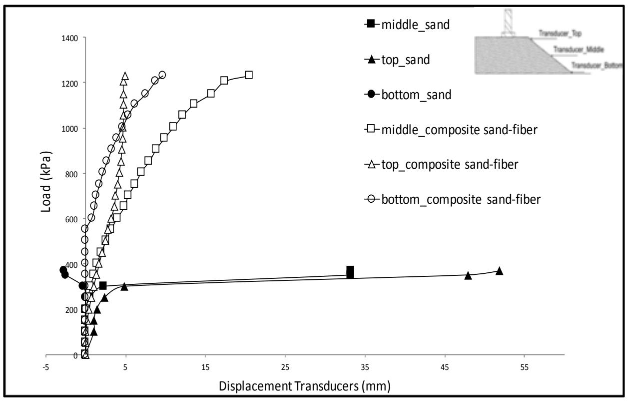

Figure 3: Horizontal displacement acquired from the transducers.

Analyzing the data, it could be seen a change in the soil behavior, where the measured horizontal displacements for the composite sand-fiber have been reduced significantly even with a higher load increase.

The data obtained in the sand test for the top transducer were higher than the middle and the base, which matches with the rupture surface formed in the soil. It is also noticed that the transducer disposed on the base of the slope suffered a contrary displacement if compared to the other transducers. This occur because prior to the rupture, the soil ran through the base transducer level, preventing their real reading.

The slope simulation test in the sand-fiber composite suffered the rupture at higher loads, supporting nearly three times the load simulation performed with sand. The horizontal deformations in composite only began to occur approximately at 300 kPa, which is the same load for rupture in the sand test, confirming that the fibers begin to act when the soil cannot support the load applied. Also, it can be noted a parallelism between the horizontal displacement curve for the top and middle up to 550 kPa.

With the obtained data, it is then possible to draw a scheme of the slope after the plate tests (Figure 4) for the sand and the sand-fiber composite. A scale ten times bigger than the actual range was used for better visualization.

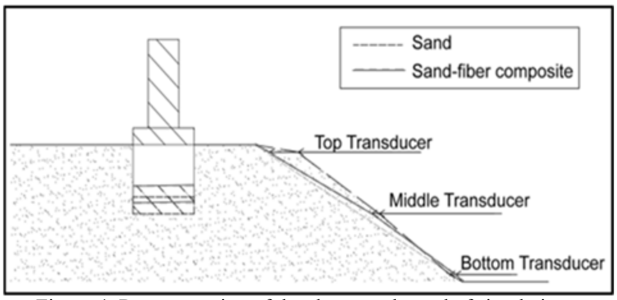

Figure 4: Representation of the slopes at the end of simulations.

Through the analysis of the figure above, it is possible to have a better comprehension about what happened during the slope simulation. In the sand simulation, the top of the slope suffered a lifting due the formation of radial cracksat surface. The same did not occur in the composite test, which suffered a "sagging" effect. It is noteworthy that, for the same load that leads the sand slope to failure, the composite slope only presented deformations without failing.

4 CONCLUSION

The following conclusions can be made from the slope simulation tests carried out for polyethylene fiber-reinforced/non-reinforced samples of a sandy soil:

1. The addition of PET fibers to the sandy matrix collaborates to an increase in resistance, decreasing the settlements measured;
2. There is a change in the mechanism of rupture, where for sand a localized rupture was found while the soil-fiber composite experienced a rupture through puncturing;
3. The horizontal displacements obtained in the slope simulation tests for the composite sand-fiber was reduced considerably if compared to the results of the sand test. For a same load application, while the sand suffered rupture, the composite only suffered deformations on its surface. The composite rupture only happened when the load was approximately three times greater than the maximum load of the sand.

The overall analysis of the results confirms the fact that PET fibers can be used as reinforcement of soils, improving its load capacity, reducing settlement and altering its behavior, when compared only to the sand.

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