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FIELD PULL-OUT TESTS ON SCRAP TIRE ARRANGEMENTS

Denise M. S. Gerscovich[1], Luciano V. Medeiros[2], Alberto S. F. J. Sayao[3] and Vinod Garga[4]

ABSTRACT

Reinforcement elements have been increasingly used in Geotechnical Engineering practice. The use of scrap tires as a reinforcement element is an attractive solution that combines the advantage of improving soil mechanical behavior, with environmental concerns. Scrap tires are globally produced in increasingly large amounts, resulting in an urban solid waste, which requires a specific disposal policy. The reinforcement system with scrap tires is made of a layer of tires filled with soil and tied together with ropes. Compared to metal strips or geotextile sheets reinforcement techniques, this system provides a better adherence between the reinforcement and the soil.

This paper presents the results of pull-out tests, performed with several arrangements of scrap tires, subjected to confining levels varying from 0,5 to 1.5 meters of soil surcharge. Most of the tests made use of tires with one sidewall removed. Considering the magnitude of the required loads, a permanent steel structure with a pull-out capacity to 500kN was constructed for the present testing program. The pull-out tests were performed with different geometric arrangements, which varied from a single scrap tire to a maximum of 18 tires.

INTRODUCTION

The technique of soil reinforcement consists of introducing metal strips or geotextile sheets into a soil mass. For stability purposes its length must extend beyond the potential failure zone. The shear stress developed at the soil-reinforcement interface reduces the horizontal thrust on retaining structures, improving their stability conditions.

Scrap tires are a solid waste, which are produced in increasing rates every year, in particular at metropolitan areas. Scrap tires have been usually disposed in landfills or tire piles with serious environmental risks. This problem may assume a larger importance in areas of tropical climate with precarious sanitation conditions. Moreover, scrap tire piles consist a serious fire hazard.

The use of scrap tires filled with soil as reinforcement element is an alternative solution that combines the advantage of improving mechanical behavior of the reinforced soil with low construction costs. Besides, it contributes to environmental policies of reducing undesirable solid wastes.

Two mechanisms are responsible for increasing the stability of reinforced retaining structures: (1) the shearing resistance of the soil-reinforcement interface, and (2) the passive resistance mobilized by the soil in front of the reinforcing element. These two mechanisms produce together a resistance at the interface soil-reinforcement, which is a fraction of the shear strength of the soil.

The scrap tire reinforcing system herein described mobilizes predominantly the interface shear resistance, which is close to the backfill soil shear strength. Simultaneously, this system is more flexible than the conventional ones, and therefore, this is an important factor to be considered in designing tire reinforced structures.

The removal of one sidewall (Figure 1) facilitates soil compaction, and therefore reduces the flexibility of soil-reinforced structures. The cut tire sidewall can be placed inside the scrap tire, before filling with soil.

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[1] Denise Gerscovich, State University of Rio de Janeiro, Brazil, R. Sao Francisco Xavier 524 –5018–A, 20550-013.

[2] Luciano Medeiros, Pontifícal Catholic University of Rio de Janeiro and UNIGRARIO, Brazil, R. Marquês de Sao Vicente 225, 22453-090

[3] Alberto Sayao, Pontifícal Catholic University of Rio de Janeiro, Brazil, R. Marquês de Sao Vicente 225, 22453-090

[4] Vinod Garga, University of Ottawa, Ontario, Canada, 161 Louis Pasteur, K6N 2G7.

To investigate the pull-out capacity of tire mats a testing program with different scrap tire arrangements was carried out in the field.

PULL-OUT TESTS DESCRIPTION

Full-scale pull-out tests apply a horizontal load on a tire mesh embedded in the backfill material. The present testing program was carried out with different arrangements of 0.6m diameter cut tires. Figure 2 illustrates the field test setup.

Considering the magnitude of the required loads, a permanent steel structure, with a pull out capacity to 500kN, was specially designed and constructed. This structure (Figure 3) has a horizontal steel frame, with a concrete base, anchored in residual soil, by two 15m inclined anchors.

Figure 1: Entire and Cut Tire

The horizontal load is applied to each individual front tire through a chain linked to a thread rod. The load application system ensures no displacements restraints to each individual tire placed in the front row. To evaluate the tire geometry influence, some tests were performed with entire tires and cut tires. To ensure horizontal leveling, the arrangements were placed over a 0.5m height soil base. Internally, the tires were manually filled up with compacted soil. The soil surcharge varied from 0.5m to 1.5m of soil height. The sandy embankment was manually compacted, and the voids between tires were carefully filled with soil. The load was activated by a hydraulic pump, which transmitted the pressure for a hydraulic piston positioned at the front of the pull-out cable (Figure 3).

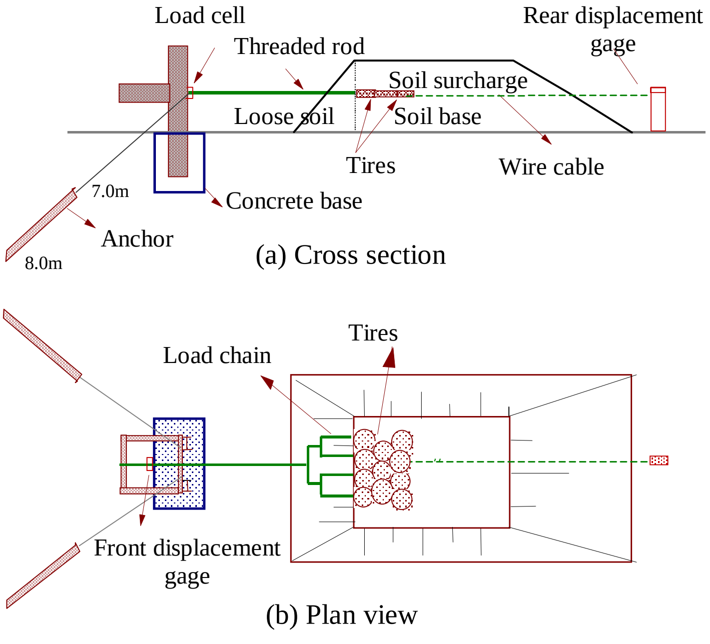


Figure 2: Equipment for Field Pull-out Tests

To permit displacements greater than the maximum piston travel (180mm), the system has a device which allows the maintenance of the constant load while the pistons are retreated and relocated prior to further load application. This procedure allowed performing tests up to the mobilization of the maximum pull-out resistance of the tire mat. The pull-out loads were manually applied at a rate of 2mm/min and the load readings were registered each 10mm of displacement, until failure was reached. The horizontal pull-out load was monitored through a KYOWA load cell BL-50TB model, with capacity of 500kN, positioned close to the hydraulic piston. The VISHAY strain indicator device, P350AZ model, was used in all tests.

To reduce the passive resistance of the soil, the soil surcharge in front of the first row of tires was kept in loose state. Figure 4 presents a view of the embankment during a test. The soil used in testing program was a poorly graded medium to coarse quartz sand (SP), with rounded to subrounded particles and strength parameters c' = 0 and $\phi' = 29^{\circ}$ (Sieira, 1998).

The horizontal frontal displacements, corresponding to the first line of tires, were measured on the thread rod. The displacements corresponding to the rear line were measured through an auxiliary nylon cable, tied to the tire at the center of the line, and extended outward the soil surcharge.

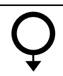
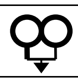
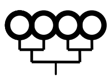
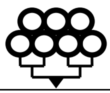
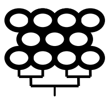
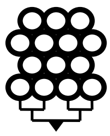
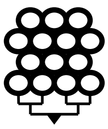
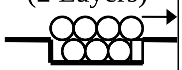
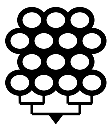
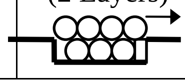
Figure 3 : Reaction Structure and Hydraulic Piston

Figure 4: Soil Surcharge in a Pull-out Test

Further details on the test equipment and methodology have been presented elsewhere (Sayao et al, 1999).

Table 1 summarizes the tire testing program. In the arrangements with more than a tire, two turns of a 6mm thick polypropylene rope was used to tie tires together.

Table 1: Pull-out testing program

Arrangement	Description	Arrangement	Description
	1 Tire		2 Tires
	4 Tires		4X3 Tires
	4X3X4 Tires		4X3X4X3 Tires
	4X3X4X3 Cut Tires (2 Layers) 		4X3X4X3 Entire Tires (2 Layers) 

ANALYSIS OF TESTS RESULTS

No significant differences have been observed in pull out displacement curves for entire and cut tires. Previous studies, however, have shown that cut tires provide a better condition for tire filling resulting in soil structures with higher compaction degrees (Medeiros el alli, 1997; Medeiros, et alli, 1999).

The influence of the number of tires, when these elements are positioned in a row transverse to the direction of movement can be evaluated from the results presented in Figure 5. The load-displacement curves exhibit irregular peaks; this pattern has been observed in nearly all tests. This behavior can be attributed to the tying process, when two turns of polypropylene rope allowed discontinuous displacements when submitted to traction loads.

Increasing the number of tires resulted in proportional larger pull-out loads and no significant influence on the displacements at failure. On the other hand, the pull-out normalized behavior with respect to the number of tires (Figure 6) indicates a distinct response for a single tire test. Test arrangements with more than one tire resulted in a constant load per tire at failure. This load is about 38% lower than the failure load for a single tire.

During the tests, the initially circular tire tends to an elliptic form consequently generating non-uniform stresses and strains at the shear interface. The average lower pull-out resistance is therefore attributed to a non-uniform mobilization of the shear stresses at failure surfaces. Besides that, arrangements with more than one tire present voids among tires which are difficult to filled with compacted soil. This may result in a looser and a less resistant soil-tire material.

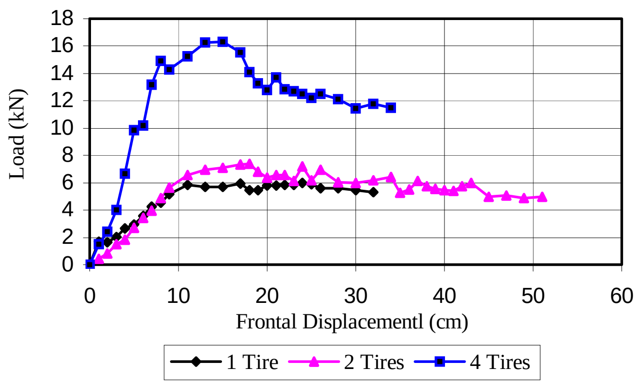


Figure 5: Pull-out Tests with Tires in a Row – 1m Soil Surcharge

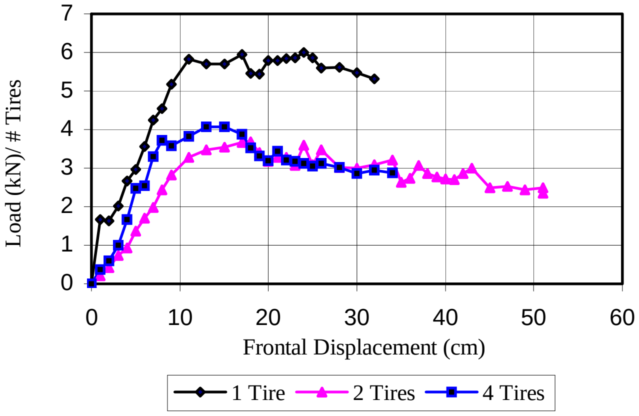


Figure 6: Normalized Behavior

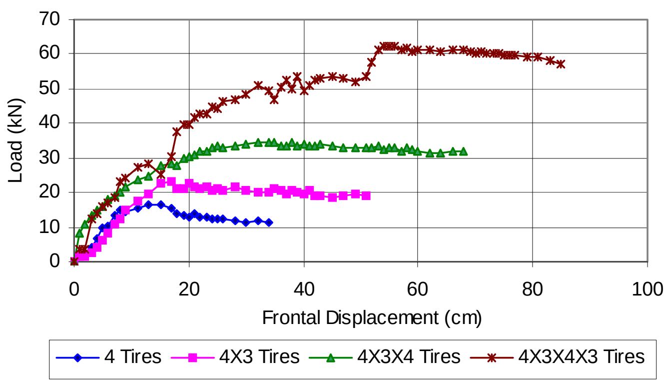


Figure 7: Tire Meshes - 1m Soil Surcharge

Previous studies have drawn similar conclusions (Medeiros et alli, 1997). This work has also shown that for single tires pull-out load displacements curves are independent of tire geometry (entire and cut tire).

The influence of the reinforcement length can be evaluated in Figure 7. The results show a proportional increase in resistance and displacement at failure, with respect to total tire numbers and number of rows. The maximum load carried by each tire is, as already expected, approximately 3,8kN.

At the beginning of the tests, the displacements are primarily due to deformations of the first row of tires. As the test proceeds, the deformations of the subsequent rows are successively initiated. For 1m soil surcharge tests, an increase of 12cm of frontal displacement at failure for each additional transversal tire row incorporated to the arrangement is observed. This result denote a standard pattern of tire group behavior. Pull-out tests performed on square geosynthetic grids, 1.8m length, under different confining stress levels, indicated lower displacement levels at failure, and registered magnitudes around 10cm (Castro, 1999).

The influence of the number of tire reinforcement lines was evaluated by testing 4X3X4X3 configurations, with cut and entire tires. These tests were performed aiming at investigating the boundary effects. The superior tire layer was placed with the center of the tires laterally displaced in relation to the layer below to promote a better interlocking. Figure 8 shows that there is no influence of this boundary condition change on the load-displacement behavior, once the pull-out resistance is strongly related to the shear strength of the soil itself. These results also indicates a negligible influence of the tire geometry (cut tire vs entire tire). Since the interface shearing interaction is dependent on several factors, it is desirable to express the interface friction in terms of Mohr Coulomb failure criterion. To evaluate the shear strength, the mobilized shear and normal stresses were computed, considering as the average total area the summation of tire areas, taking in account both faces of the reinforcement layer. Figure 9 shows the maximum shear stress values versus normal stress, obtained for the pull-out testing program. The single tire tests data were not included, due to the sensitive difference of an individual tire response and the tire group behavior. This figure

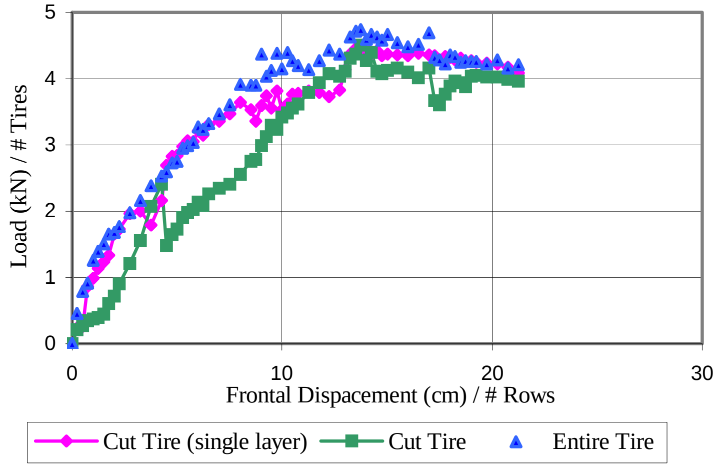


Figure 8: Normalized Behavior of 4X3X4X3 Tire Meshes – 1m Soil Surcharge

also shows the linear envelope, which gives the best fit of the test results. The small amount of tests for high confining stress level inhibits a more detailed discussion of the test results. For the present field tests, the strength envelope indicates a nearly null linear intercept and an interface friction (δ) equal to 23°. The relationship among the interface soil-reinforcement friction and soil friction (tanδ/tanϕ) is 0.77, which represents a 20% reduction of shear strength of the soil.

For pull-out tests, the main interaction mechanisms between soil and reinforcement are associated to the soil shearing on plane surfaces of the reinforcement and soil bearing (passive resistance) on surfaces which are normal to the direction of relative movement. The significance of each one of these components depends on the magnitude of displacements, which are needed for their mobilization.

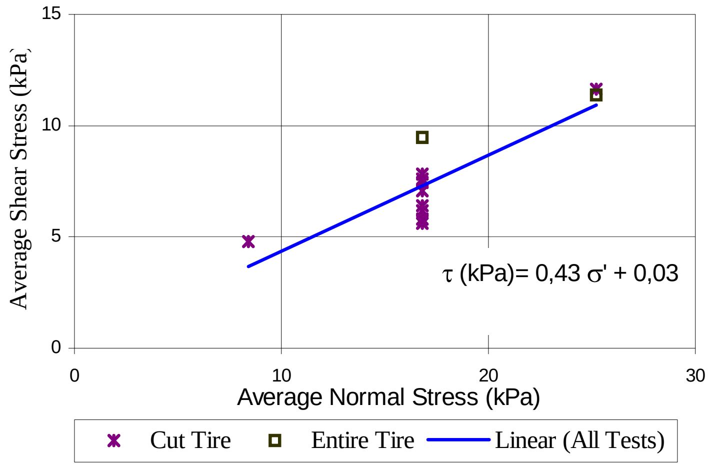


Figure 9: Average Strength Envelope

Usually, the strain levels achieved fully mobilizes interface friction components, but are insufficient to complete mobilize passive resistance. For the current testing program, the relative influence of passive resistance has been minimized since the soil surcharge ahead the tire layers was placed in loose state.

The apparent friction coefficient, defined as the ratio between the maximum shear stress and normal stress (τ_{max}/σ), varied from 0.4 to 0.7 and are compatible with values obtained with conventional reinforcement elements (Mitchell and Villet, 1987).

CONCLUSIONS

Pull-out field tests have been performed with different scrap tire arrangements, tire geometry (cut and entire tires). The tests were restricted to confining stress levels, varying from 0,5m to 1,5m surcharge.

No significant differences have been observed in pull out displacement curves for entire and cut tires. Previous studies, however, have shown that cut tires provide a better condition for tire filling resulting in soil structures with higher compaction degrees.

Tests performed with single tires have indicated a 7kN pull-out resistance. For tire mats, the average pull-out value was approximately 4kN per individual tire. The lower pull-out resistance was mainly attributed to a non-uniform mobilization of the shear stresses at failure surfaces. The influence of soil compaction in the pull-out results was considered negligible.

Except for single tire tests, the pull-out load-displacement curves could be normalized with respect to the number of tires. The results for 1m soil surcharge indicated, as a standard tire group behavior, an increase of 12cm of frontal displacements at failure for each additional transversal tire row incorporated to the arrangement.

The computed shear resistance at the interface soil-tire has indicated a small reduction compared to soil's shear strength. No significant influence of the passive resistance mobilized by the soil in front of the reinforcing element has been observed on the tests herein presented

Scrap tire arrangements appears to be an attractive alternative for soil reinforcing. Due to tire mechanical properties and construction procedures, the whole soil reinforced structure shows a larger flexibility when compared to conventional techniques.

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