Field pullout tests of scrap tire reinforcement layers under different-soil surchages

Essais d'arrachement sur assemblages d'élements de pneumatic sous, différent hauteur de remblais

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ABSTRACT: Reinforcement elements have been increasingly used in geotechnical projects. The use of scrap tires as reinforcement elements is an attractive solution that combines the advantage of improving soil mechanical behavior, with reducing environmental concerns with scrap tires disposal piles. Scrap tires are produced in large amounts, resulting in an urban solid waste. The reinforcement system with scrap tires is made layers of tires filled in with soil and tied together to form a mat. This paper presents the results of pullout tests, performed with several arrangements of scrap tires, subjected to confining stress levels within the range of 0.5 to 2.5 meters of soil surcharge. These arrangements varied from a single scrap tire to a maximum of 18 tires. Most of the tests made use of tires with one sidewall removed. The results suggest that a minimum pullout tire capacity of 4kN per surcharge height can be used for engineering purposes.

RÉSUMÉ: Les éléments du renforcement ont été utilisés dans la geotecnique de plus en plus. Introduire pneus usés comme éléments du renforcement est une solution attirante qui combine l'avantage d'améliorer le comportement mécanique du sol, avec la reduction de la préoccupation de l'entreposage de pneus usés. Les pneus sont produits dans les grands montants et résultent en déchets solide urbain. Le système du renforcement avec les pneus est fait d'une couche de pneumatic remplie de sol et attaché avec cordes. Cet article présente les résultats d'essais d'arrachetment, exécutés avec diferent assemblages de pneus, disposés sous une épaisseur de rembai qui varient de 0,5 à 2.5 mètres. Les assemblages du pneu ont varié d'un pneu seul à un maximum de 18 pneus. La plupart des essais ont fait usage de pneus partiellement découpés. Les résultats suggèrent que par chaque élement de pneumatic un effort minimum de traction de 4kN par hauteur de remblais peut être utilisé en ouvrages de génie-civil.

1 INTRODUCTION

Soil reinforcement technique introduces elements into the ground, which are capable to resist tensile loads.

Scrap tires are solid wastes, 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 present 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.

2 PULL-OUT FIELD TESTS

The experimental program presented in this paper consists of a serious of present full-scale pullout tests which applied horizontal loads to tire meshes embedded in a backfill material. The tires were tied together with a double loop of a 6mm thick polypropylene rope.

Field test setup and monitoring details have been presented elsewhere (Gerscovich et al., 2000).

For the present testing program, the soil surcharge ranged from 0.5m to 2.5m of soil height. The sandy embankment was mechanically compacted with the use of the bulldozer shovel. Internally, the 0.6m diameter tires were also filled up with compacted soil. Figure 1 shows a view of a test.

To evaluate the significance of the tire filling material, two tests were carried out having the tires partly filled with a stiffer material. The stiffer material was either a soil-cement mixture (10% in weight) or an unreinforced concrete slab placed in the midheight of the tire. The thickness of this slab was smaller than the tire height to guarantee that shear mobilization takes place along a soil-soil contact.

The removal of one sidewall (Fig. 2) facilitates soil compaction, and therefore reduces the flexibility of soil-reinforced structure. The tire sidewall removed was placed inside the scrap tire, before soil compaction.

Figure 1. Field pullout test view.

Figure 2. Full tire and sidewall removed tire.

Table 1: Pullout testing program.

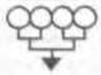
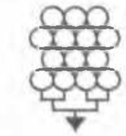
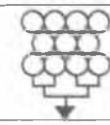
Arrangement	Description	Arrangement	Description
	1 Tire		4 Tires
	4X3 Tires		4X3X4X3 Tires
	4X3X4 Tires		

Table 1 summarizes the pullout tire arrangements of the testing program.

A well-graded sand (SW) was used having strength parameters c' = 4,3kPa and $\phi' = 31.7^{\circ}$. The unit weight of the compacted soil was 16.8kN/m^3 with relative density of 42% and 8.2% soil moisture.

3 ANALYSIS OF TEST RESULTS

Table 2 shows a summary of the pullout test results for the different tire arrangements

No significant differences have been observed in pullout displacement curves for entire and cut tires (Gerscovich et al., 2000).

3.1 *Pullout resistance*

Increasing the number of tires resulted in proportional larger pullout loads. Figure 3 shows the pullout load normalized behavior with respect to the number of tires. Each curve refers to specific vertical stress levels and to different types of tires (full

Table 2. Pullout test results.

Arrangement	H* (m)	P_f** (kN)	P_f/ # Tires (kN)	Δ_f*** (m)
1 cut tire	0.5	17.2	17.2	0.11
	1.5	36.5	36.5	0.20
	2.5	58.8	58.8	0.15
1 full tire	1.0	22.6	22.6	0.12
	2.5	54.3	54.3	0.20
4 cut tire	0.5	34.8	8.7	0.18
	1.5	68.5	17.1	0.18
	2.5	123.2	30.8	0.24
4 full tire	1.0	24,5	6.1	0.24
	2.5	108.9 4	27.2	0.30
4 X 3 cut tire	0.5	37.4	8.7	0.20
	1.5	88.2	17.1	0.33
	2.5	127.6	30.8	0.40
4 X 3 full tire	1.0	50.0	7.1	0.34
	2.5	128.7	18.4	0.40
4 X 3 X 4 (cut tire)	0.5	55.1	5.0	0.36
	1.5	98.1	8.9	0.47
soil-cement	1.5	103.3	9.4	0.43
4 X 3 X 4 (full tire)	1.0	60.0	5.5	0.56
	2.5	142.2	12.5	0.54
4 X 3 X 4 X 3 (cut tire)	0.5	78.5	5.6	0.40
	1.5	104.2	7.4	0.54
concrete slab	1.5	98.5	7.0	0.34
4 X 3 X 4 X 3 (full tire)	1.0	78.5	5.6	0.75

*H = surcharge height
**P_f = pullout force at failure
*** Δ_f = frontal displacement at failure

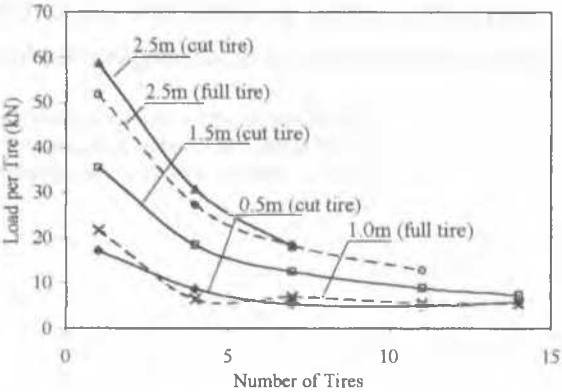


Figure 3. Maximum load normalized behavior.

tire or cut tire). For a given surcharge load, the pullout capacity per tire converges to a certain value, as the number of tires increases. For surcharges less than 1.5m height, this value is reduced to 6kN. For higher surcharges, this value is not clearly defined due to the limited amount of test arrangements used in the present testing program. Although, one can comfortably assume that these curves converge to higher values.

The ratio between the normalized load and surcharge height is shown in Figure 4. With the exception of the tests with 0.5m surcharge height, the pullout load per tire can be represented by a single curve.

Previous pullout tests (Gerscovich et al., 2000) and tests performed by O'Schaughnessy & Garga (2000) are also plotted in Figure 4.

O'Schaughnessy & Garga (2000) reported pullout tests with different configurations of mat tires embedded in 0,5m to 1,0m sandy backfill. Their test setup is similar to the one presented in this paper. Their results emphasize the influence of tire mat configuration. Linear tire grids with a single row transverse to the direction of the applied load, produced higher pullout resistance than the one obtained with a linear tire grid aligned with the applied load. For sake of comparison between both testing programs, the results shown in Figure 4 disregard pullout tests with a single tire in the first row.

The pullout behavior, presented in Figure 4, apparently indicates that for tire arrangements with more than 14 tires, the load per tire/surcharge height for each testing program approaches a constant value.

The small differences on the testing program results can be associated to the influence of the different grain size distributions and relative densities of the backfill.

The reported experimental results suggest that a minimum pullout tire capacity of 4kN per surcharge height (m) can be used for engineering purposes.

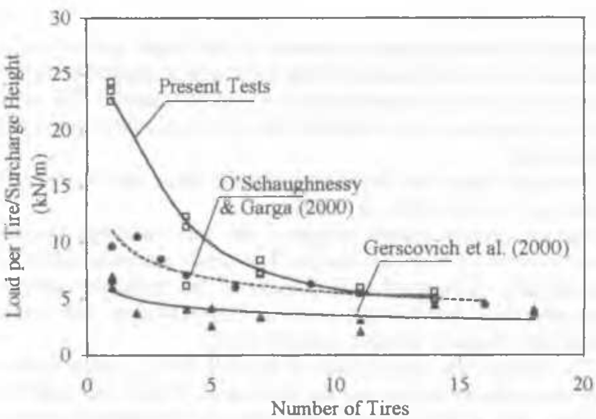


Figure 4. Normalized behavior with respect to number of tires and surcharge height.

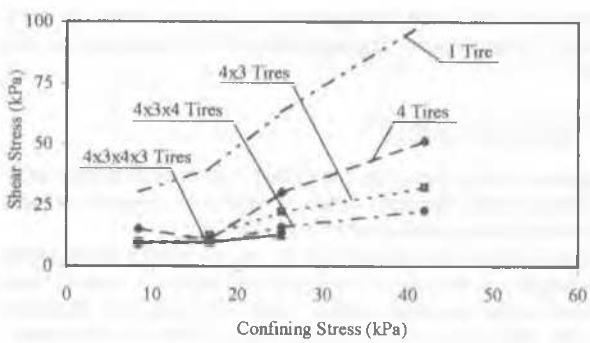


Figure 5. Maximum shear stress vs. confining stress.

Figure 5 shows the maximum shear stress versus normal stress obtained for the pullout testing program.

The mobilized shear stresses were computed taking into account that the shear mechanism occurs on both horizontal planes, between the soil and the reinforcement layer. The eventual horizontal thrust in the front of the tire mat and lateral shearing resistance were considered negligible. Due to irregular geometry of tire arrangements, some uncertainties arise in the definition of the precise contact area involved in the shear process. The present paper considered that the surface contributing to the shear strength is the horizontal area that confines all tires.

The pullout resistances monitored in single tire tests were consistently higher than the ones registered with tire mats. This behavior can be attributed to the existence of a stronger influence of lateral confinement in a single tire arrangement. In addition, arrangements with more than one tire present voids among tires, which are difficult to be filled in with compacted soil. This may result in a looser and a less resistant soil-tire material (Gerscovich, et al., 2000).

For low confining stress, less than 17kPa, the shear strength is approximately constant. This result was consistent with data reported by O'Shaughnessy & Garga (2000). The high values of shear strength, at low confining stresses, may be attributed to an extra energy being used to dilate the soil. For higher stress levels, the pullout resistance increases linearly with the confining stress. It is therefore reasonable to conclude that the failure envelope in bilinear.

For tire arrangements with more than 4 tires, the best fit failure envelope for normal stresses beyond 17kPa leads to Mohr-Coulomb interface friction angle (δ) of 28.3° and a negligible linear intercept. The pullout resistance (P_R) can, therefore, be evaluated with the following equation:

$$P_R = 2A_{mob}\sigma'_v \tan\delta \qquad (1)$$

where A_{mob} = mobilized contact area; σ'_v = vertical effective stress and δ = interface friction angle.

O'Schaughnessy & Garga (2000) proposed the following equation to estimate pullout capacity per 1.2 meter width (2 passenger tires) of tire reinforcement, P_T, under drained conditions:

$$P_T = \frac{5}{3}\alpha_b\sigma'_v \tan\phi' L_e \qquad (2)$$

where α_b = bond efficiency coefficient; σ'_v = effective vertical stress; ϕ' = effective friction angle of the backfill and L_e = embedded length of resisting zone behind the potential failure surface. Considering pullout capacity per meter width of tire reinforcement, P'_T, Equation 1 can be rewritten as:

$$P'_T = 2\alpha_b\sigma'_v \tan\phi' L_e \qquad (3)$$

Based on Equation 3, figure 6 shows the bond efficiency coefficient (α_b) vs. reinforcement length, for the present testing program results. For arrangements with more than 4 tires, the

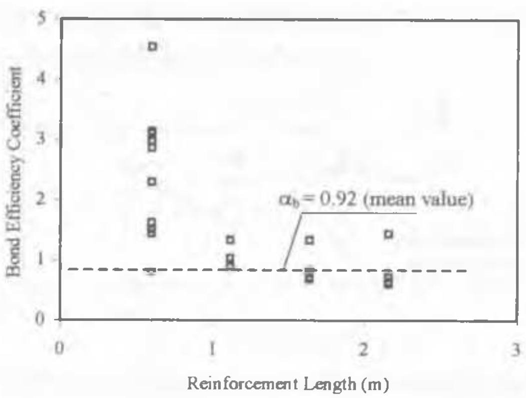


Figure 6. Bond efficiency coefficient vs. reinforcement length.

data indicate a mean α_b value of 0.92 with a standard deviation of 0.27.

Equation 1 and 3 show that the bond efficiency coefficient is therefore the ratio between the average shear strength mobilized over the total length of the tire mat reinforcement and the peak shear strength of the soil.

$$\alpha_b = \frac{\tan\delta}{\tan\phi'} \qquad (4)$$

The interaction between soil and tire mat reinforcement is predominantly governed by friction along the horizontal shear plane. The relationship among the interface soil-reinforcement and soil friction angles (tanδ/tanφ) is equal to 0.87. The small deviation between α_b values (Fig. 6 and Eq. 4) can be predominantly attributed to the assumption of mobilized contact area (A_{mob}).

3.2 *Frontal displacement at failure*

At the earlier stages 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. Also it was observed that the rope knots connecting adjacent tires were tightened with the load application, resulting in an unforeseen displacement. These displacements were visually observed after the completion of the tests and ranged between 0.02m to 0.04m. The monitoring procedure did not allow the identification of each component of frontal displacement throughout the test.

For the present testing program, the frontal displacements, at failure, were normalized with respect to the number of rows (Fig.7). As the number of row increases, the normalized frontal displacement reduces slightly. This pattern can be assigned to the increasingly restriction of movement due to the presence of a greater number of tire connections.

For tire mats with 4 rows, the normalized frontal displacements show values around 0.1m to 0.2m. Due to the limited number of tests the influence of vertical stress level is not conclusive.

O'Schaughnessy & Garga (2000) results are also plotted in Figure 7. Their data do not significantly depart from the ones obtained in the present experimental program and indicate an average normalized frontal displacement of 0.15m.

Previous tests (Gerscovich et al., 2000), with 1m surcharge height, have registered an increase of 0.12m of frontal displacement, at failure, per each transversal tire row. This is result is of the same magnitude of the ones herein.

Pullout tests on scrap tire mats produce load-displacement curves that do not exhibit failure peaks. On the contrary, it was noticed the presence of some irregular peaks, which were attributed to discontinuous displacements of the connection provided by polypropylene rope (Gerscovich et al., 2000).

Although the shape of load-displacement curve enables one

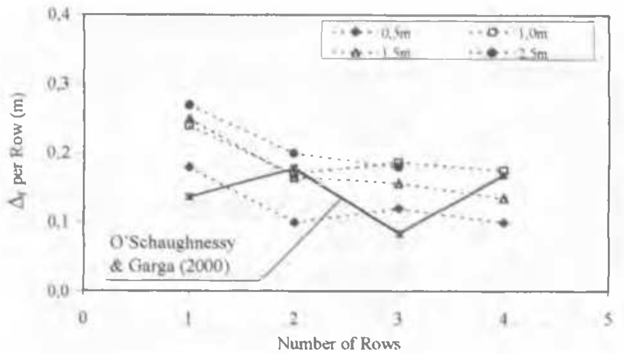


Figure 7. Frontal displacement at failure (Δ_f) per number of rows, for different surcharge heights.

to clearly define the maximum pullout load, it is troublesome to depict the corresponding frontal displacement. To minimize the uncertainties associated with the displacement definition, the authors consider that it is adequate to draw conclusions related to deformation based on frontal displacement at 90% of the maximum pullout load. This procedure facilitates the interpretation of the displacement and it was used to build the curves presented in Figure 8. The shape of these curves is similar to the ones observed in Figure 7, differing only on the magnitude of the displacement. For arrangements with greater number of rows, the deviation between the different curves reduces to a range from

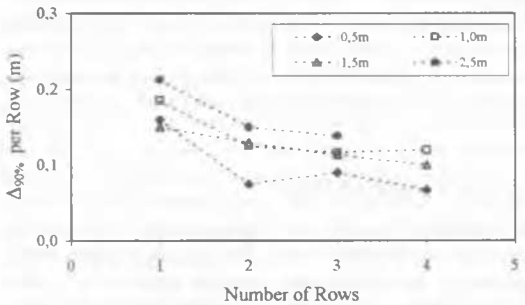
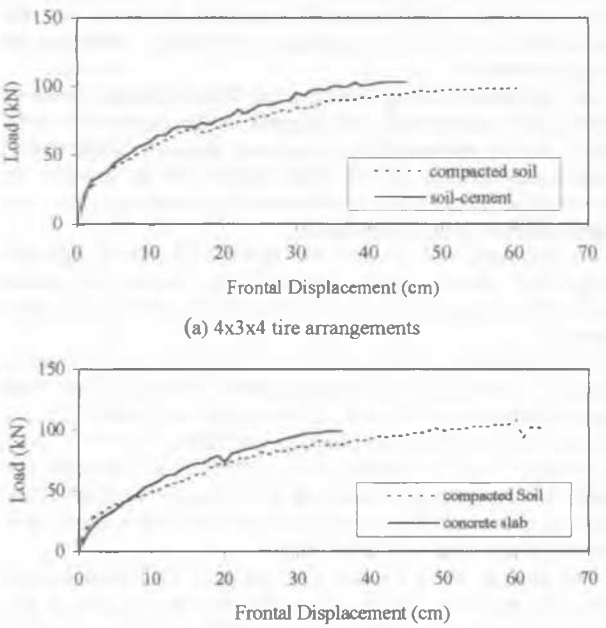


Figure 8. Frontal displacement at 90% of the maximum pullout load per number of rows, for different surcharge heights.



(a) 4x3x4 tire arrangements

(b) 4x3x4x4 tire arrangements

Figure 9 Influence of tire stiffness.

0.07m to 0.12m, which is significantly narrower than the band obtained from assumed displacements at the maximum pullout loads.

3.3 *Internal tire stiffness*

The present testing program comprised 2 extra pullout tests with tire arrangements internally filled in with a soil-cement mixture (10% in weight) or unreinforced concrete slab.

Figure 9a shows the test results for 4x3x4 arrangements under 1.5m height soil surcharge. No significant differences have been observed in the maximum pullout load, but it has been recorded an 8.5% reduction of the corresponding frontal displacement. The test performed with a concrete slab as an internal reinforcement (Fig. 9b) produced a stiffer tire mat behavior and a 37% reduction of frontal displacement at failure.

The stiffness of the soil mat does not change significantly the pullout as long as the tests set up provides conditions that guarantees that the shear mobilization takes place along soil-soil interface.

4 CONCLUSIONS

This paper presented results of a comprehensive series of field pullout tests of scrap tire reinforcement layers, under soil surcharges ranging from 8.6kPa to 42kPa. Previous pullout tests (Gerscovich et al., 2000) and tests performed by O'Schaughnessy & Garga (2000) have been considered in the analysis.

The pullout behavior with respect to the number of tires indicated a distinct response for a single tire test. Increasing the number of tires resulted in proportional larger pullout loads.

The interaction between soil and tire mat reinforcement is predominantly governed by friction along the horizontal shear plane. The ratio between the average shear strength mobilized over the total length of the tire mat reinforcement and the peak shear strength of the soil ($\tan\delta/\tan\phi$), defined as bond efficiency coefficient (α_b), was equal to 0.9.

In spite of the limited amount of tire arrangements, the results suggested for practical purposes a minimum resistance value of 4kN per tire / surcharge height (m) and 0.12m of maximum frontal displacement, at failure, per each transversal tire row. The pullout capacity per meter width of tire reinforcement can be estimated by Equation 3.

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