International Journal of Engineering, ISSN/ISBN: 00207225,revised papper 28/03/2004,

SCRAP TIRE: A CIVIL ENGINEERING MATERIAL

D.M.S. Gerscovich and A.C.C.F. Sieira

State University of Rio de Janeiro,
Rio de Janeiro, Brazil, deniseg@uerj.br, sieira@uerj.br

L.V. Medeiros

Gama Filho University, Catholic University of Rio de Janeiro
Rio de Janeiro, Brazil, lmedeiros@globo.com

A.S.F.J. Sayão

Catholic University of Rio de Janeiro,
Rio de Janeiro, Brazil, sayao@civ.puc-rio.br

Abstract Industrial societies produce scrap tires at increasing rates every year, generating a large amount of a non-degradable urban solid waste. Stockpiles of scrap tires are exposed to constant danger of fire, besides they may induce propagation of insects and diseases. Environmentally acceptable management options to deal with scrap tires include: Reduction, Recycle, Recover and Re-use. This paper describes a comprehensive research project on tire waste utilization for Civil Engineering purposes. A prototype soil-tire retaining wall, 4m high and 60m length was constructed and monitored. The use of scrap tire mats as soil reinforcement has also been investigated by a series of field pullout tests, with several arrangements of scrap tire mats, subjected to different confining levels. The research indicates that the use of scrap tires can be an attractive low cost alternative in soil stabilization projects.

Key Words *scrap tires, retaining wall, field instrumentation, field pullout tests.*

1. INTRODUCTION

Industrial societies produce scrap tires at increasing rates every year. Presently, the disposal of tires assumes impressive volumes, with a world production over 800 millions of scrap tires annually. It is estimated that approximately 3 billion used tires are deposited in reclaimed areas. Tires are non-degradable and, due to their shape, quantity and compaction resistance, vast landfill areas are required. As a result, expensive waste management costs are incurred, particularly in metropolitan areas where the availability of large landfill sites is limited. Stockpiles of scrap tires are exposed to constant danger of fire and also induce propagation of insects and diseases, particularly important in tropical environments with poor sanitary conditions. The accumulation of moisture in scrap tires in combination with heat and dark environment provides an excellent environment for breeding of vermin.

Tires are composed of two sidewalls and a tread. They consist of a rubber or polymer cover strongly reinforced with fibber or metals, with a very high tensile strength. Their mechanical properties remain available even after its ordinary life has expired.

The environmentally acceptable management options include the following:

- *Reductio*n as a consequence of a technological developments that increases of service life,
- *Recycle* by cutting to make new products such as floor mats, roadbeds and tracking fields, etc. or by grinding to make asphalt mixtures, rubber plastic compounds, etc.
- *Recover* the raw material to manufacture new products such as tire-derived fuel, etc.
- *Re-use* by retreading or as a civil engineering material.

Considering the frequent use of steel meshes embedded in the tire, a significant portion of the above applications cannot utilize such tires, therefore reducing the reutilization of an expressive number of scrap tires. Processing used tires requires a significant amount of financial investment as well as a strict control on air emission. The percentage of tire reutilization varies according to the industrial setting of each region, and is limited to the range of 15% to 45% of used tires.

The re-use of the whole tire as a Civil Engineering material therefore appears to be an attractive alternative to reduce the potential hazard on the environment.

It has been also observed that tires embedded in earthfills do not apparently affect the environment. Water samples collected from a drainage system installed below a tire-reinforced earthfill showed no significant adverse effect on water quality over a period of 2 years.[1].

One of the first applications of the use of tires in Civil Engineering practice dates from the decade of 70, with the reconstruction of a highway embankment, reinforced with tires, in the north of California [2]. The embankment was constructed with horizontal layers of tires, vertically spaced of 0,60m and interlinked with metal loops.

The primary researches related to the use of the technique of soil-tires (denominated "PNEUSOL") were developed in France. A 5m height and 10m long experimental wall was constructed in Langres [3]. The results of this experiment demonstrated the feasibility of execution of soil-tires retaining structures.

After these experiences, other retaining walls were built. Long [4] reported a wall in Ferrupt, with 54m of extension and 5m of height, and the one in Bussang, constituted of 6 different sections summing a total of 650m of length and up to 7m of height. All available data in the literature referred to the details of the use of the technique, with little information regarding the deformability of the soil-tires material.

In the 90´s, a comprehensive research project on tire waste utilization has been carried out simultaneously in Rio de Janeiro, Brazil [5], and Ottawa, Canada [1, 6, 7, 8, 9]. The project involved the construction of two prototypes earth retaining walls and the execution of field pullout tests, to evaluate the use of tires as soil reinforcement.

Engineering properties of soil tire mixtures have also been investigated in the 90’s. Laboratory and prototype tests have been performed aiming at studying the suitability of the mixture as: (i) cover material for sanitary landfills; (ii) lightweight fill material; (iii) hydraulic barriers to groundwater flow [10, 11, 12].

This paper reports the main results of the research project, developed in Rio de Janeiro, Brazil, which intends to promote the use of scrap tires in gravity and reinforced retaining walls.

2. SCRAP TIRE RESEARCH PROJECT

2.1 Gravity Retaining Wall Gravity retaining walls are made to resist earth lateral thrust, and their stability against overturning and sliding relies on the weight of the structure.

To investigate the geotechnical behavior of a soil-tire gravity walls; a fully instrumented retaining wall, 60m length and 4m height was built (Figure 1). The tires where horizontally placed side by side, in successive layers, tied together to make a mat, and filled in with compacted soil. An additional 2 m surcharge load of soil was placed after the completion of the wall.

To provide a uniform arrangement only car passenger tires (0.60m of external diameter, 0.30m of internal diameter and 0.20m of thickness) were utilized.

Tires with one sidewall removed (Figure 2) were also used aiming at achieving a better condition for internal compaction. Figure 3 shows the cutting tire machine, which was used to remove the tire sidewall.

The reinforced wall was comprised of four different sections, as shown in Figure 4, with the following characteristics:

- *Section A*: full tires, tied together with a 6mm thick polypropylene rope;
- *Section B*: tires with top sidewall removed, with the same cross section, rope connection as in section A.
- *Section C*: tires with top sidewall removed, with the same cross section in section A, but tied with a 2mm diameter plastic coated galvanized zinc wire;

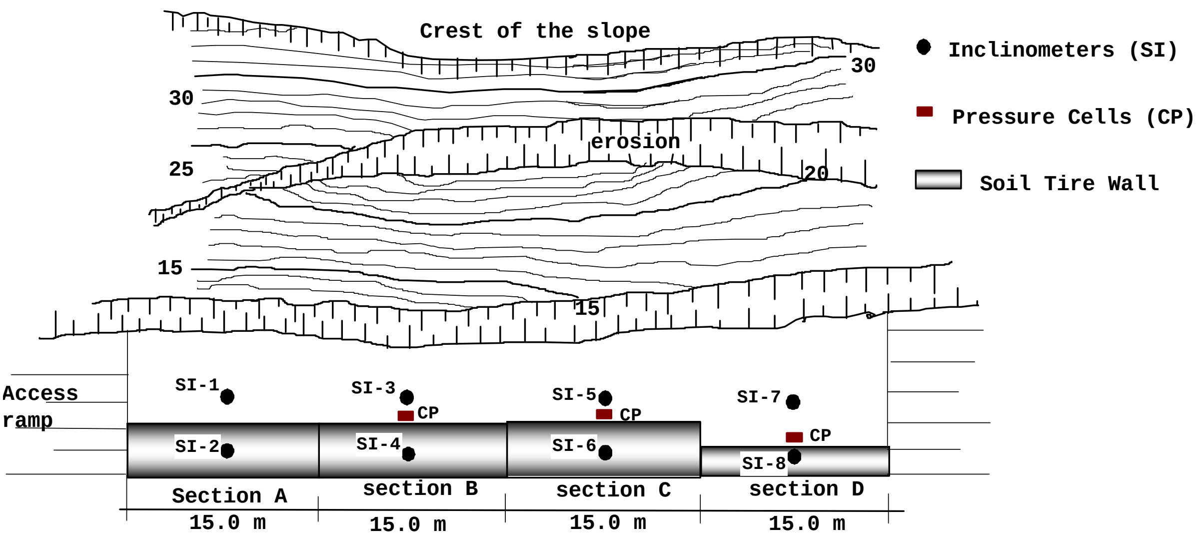


Figure 1. Site Plan and Instrumentation Location

Figure 2. Full and cut tires**.**

Figure 3. Machine for cutting tires**.**

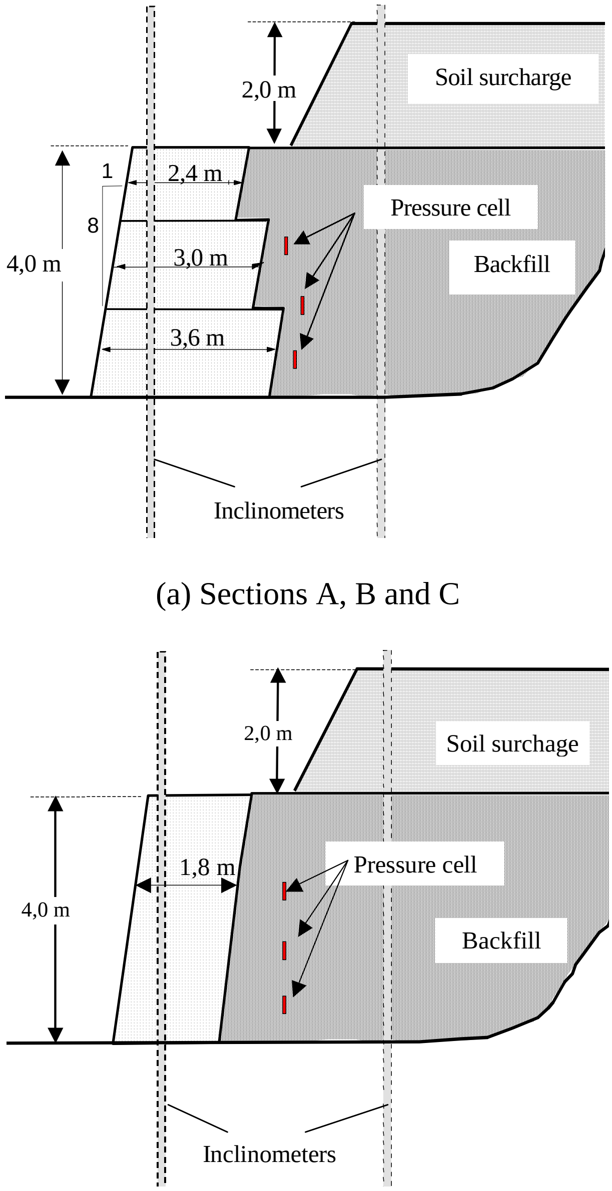
• *Section D*: tires with top sidewall removed, tied together with a 6mm thick polypropylene rope, with a narrower cross section.

The field instrumentation comprised inclinometers and pneumatic earth pressure cells (Figure 4).

The retaining structure was built in the following sequence:

i) The base surface was cleaned and leveled.

ii) The tires were tied to adjacent four tires by a single turn of rope or wire. The front row of tires was tied together by two turns of the rope or one turn of the wire



(a) Sections A, B and C

(b) Section D

Figure 4. Cross sections and field instrumentation

iii) There was no connection between tires of different layers of tire meshes.

iv) Soil compaction was done using manual labor and light machinery.

v) Successive tire layers were placed with the center of the tires laterally displaced (30cm) in relation to the layer below to promote the interlocking of the layers.

The construction has progressed satisfactorily although some delays occurred due to periods of intensive rain.

Figure 5 illustrates different stages of soil-tire wall construction. At the end, the external face may be protected with vegetation or a thin layer of asphalt or concrete. This protection is recommended not only for aesthetic reasons, but also to minimize the possibility of fire or ultraviolet light degradation. Also, this protection prevents erosion of soil placed at the exposed tire at the wall face.

(a) Initial stage, full tires section

(b) Initial stage, section of cut tires tied with wire

(c) Intermediate stage, section of cut tires tied with wire

(d) Manual operations for filling tires

(e) Intermediate stage, front face

(f) End of construction

Figure 5. Soil-Tire retaining wall construction

Details of the construction and monitoring of the wall have been presented elsewhere [13, 14, 15].

2.1.1 Materials The construction of the soil-tire wall consumed approximately 15,000 tires and made use of light compaction equipment and soil locally available. Soils with poor geotechnical characteristics may be used in a gravity structure, because its role is primarily to provide weight.

The soil at the experimental site is a well graded clayey silty-sand (Unified Soil Classification: SC), weathered from a gneissic rock mass. Table 1 shows the geotechnical characterization and Figure 6 shows the grain size distribution of local soil.

Table 1. Geotechnical characterization of local soil

Natural soil	
Liquid limit (%)	46.0
Plastic limit (%)	31.0
Water content (%)	20.0
Specific gravity of solids	2.72
Compacted soil	
Unit weight (kN/m³)	17.5
Void ratio	0.83

Drained triaxial tests in saturated samples have indicate, for confining pressures ranging from 50kPa to 150kPa, no cohesion and a friction angle of 29^o. Direct shear tests in unsaturated condition showed a greater cohesion equal to 13kPa [5].

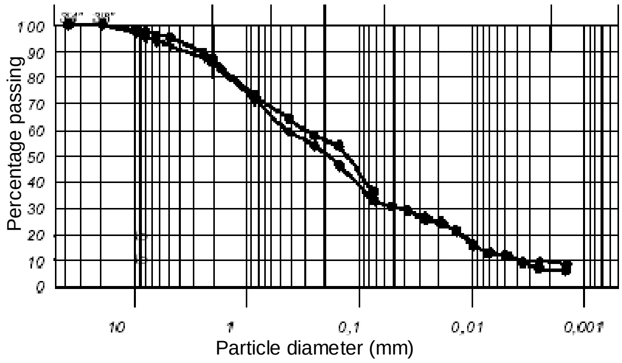


Figure 6. Grain size distribution of local soil

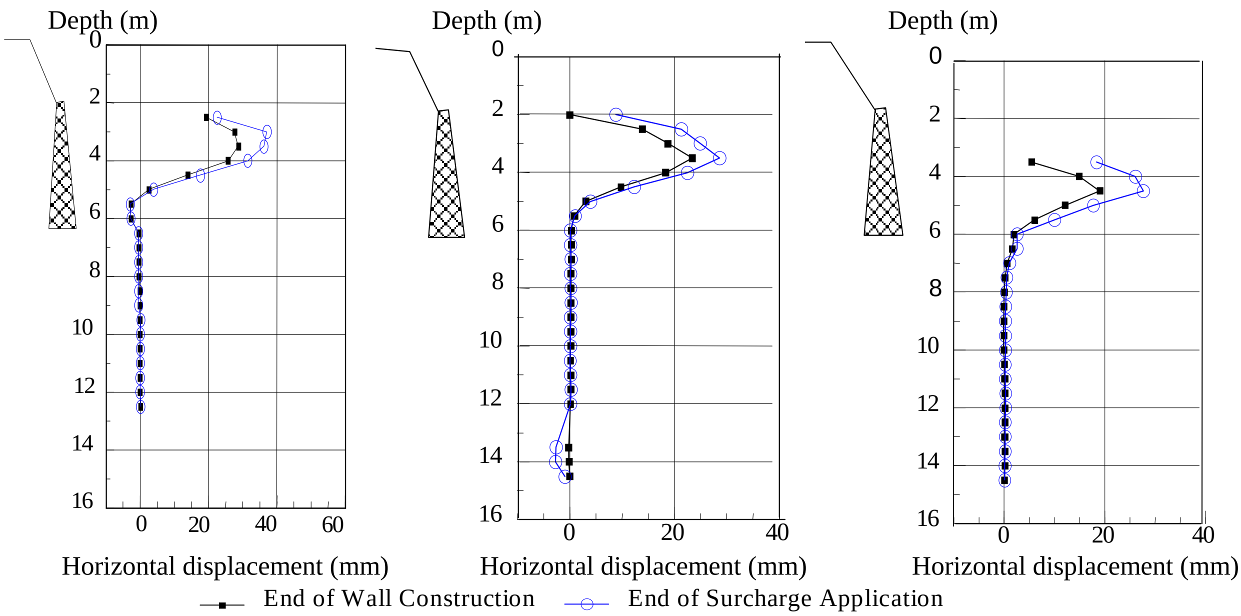
The stability of the wall is a function of its specific weight. In this case it depends on the type of tire to be used. A series of density tests was performed in concrete lined pit, shown in Figure 7. This pit accommodates three layers of nine tires. The construction procedure used in the field was reproduced inside the pit with full tires and cut tires. The computed specific weights were 16.2kN/m^3 and 15.4kN/m^3, respectively for cut and full tires. It was therefore observed a reduction of 6.2% on the specific weight of the retaining wall built with cut tires when compared to the specific weight of the backfill. For a wall built with full tires the reduction observed was 11.4%.

Figure 7. Field Density Tests

2.1.2. Field Results Figure 8 present profiles of horizontal displacements measured at the end construction and after the placement of soil surcharge. The maximum horizontal displacement occurred within the middle third of the wall height and ranged from 0.7% (Section A) to 0.5% (Section C) of the wall height (H).

Horizontal displacement measurements in section D have indicated that installation problems might have occurred. Therefore, their results were disregarded.

The soil-tire experimental retaining wall showed a higher flexibility than conventional gravity walls, which exhibits displacements around 0.2%H to 0.4%H. However, the observed movements for the present tire reinforced wall were kept within reasonable limits. A closer tightening of tire connections, with the use of plastic coated wire, resulted in about 30% reduction of the maximum horizontal displacement, when compared to tire connections with rope.



(a) Section A (b) Section B (c) Section C

Figure 8. Horizontal displacements *vs.* depth

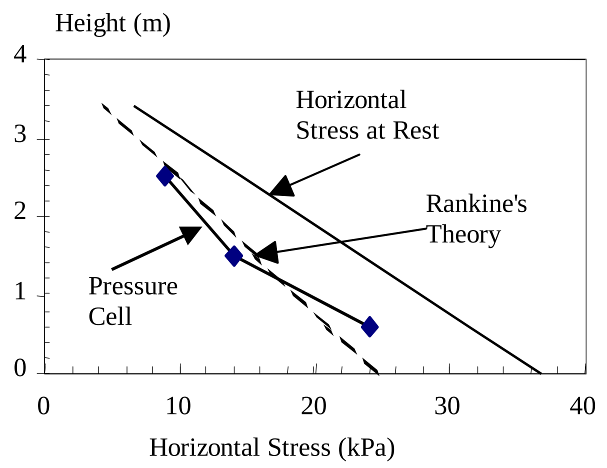
It is worthwhile to note that the application of the surcharge in section A, produced additional lateral displacement concentrated near the zone of the maximum horizontal displacement, indicating some bulging around the middle of the height. This feature suggests the existence of a relative movement between the tires in the middle, and the tires near the top and the bottom of the wall. This behavior is significantly different from the common rotation around the base, which is observed on conventional gravity walls.

The application of the surcharge in section C, produced a rigid block movement from the top of the wall to approximately 75% of its height, and practically no additional movement was monitored below this level.

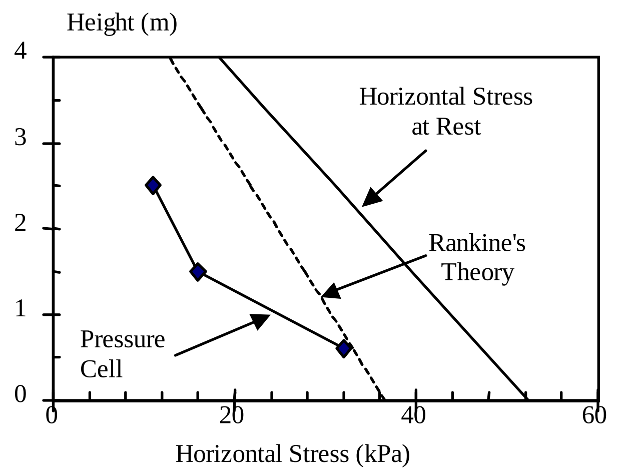
Three levels of pressure cells, located 0.6m, 1.5m and 2.5m from the base of the wall, were installed behind the wall at sections B, C and D. The earth pressure was not monitored behind Section A. The top earth pressure at section D malfunctioned since the early stages of the construction, therefore their readings were disregarded.

Figure 9 presents earth pressure readings in Section B, at the end of construction and at the end of surcharge application. These results, which have a similar pattern to the ones in sections C, are compared to Rankine's active and at rest earth pressure distributions. The theoretical curves were computed based on strength parameters obtained from laboratory tests [5]. The earth pressure coefficient at rest was inferred from Jaky's equation [16]. Due to the horizontal displacements, the measured horizontal stresses at end of construction are lower than at rest horizontal stresses, and show a reasonable agreement with Rankine's theory. However, at the base of the wall, an increase of horizontal stresses may be noted. This, in connection with the lateral displacement measurements, indicates that the flexibility of the wall promotes an expressive load transfer from the middle part to the edges of the backfill.

After application of surcharge, stresses were below Rankine's active earth theory, for the first three meters of the wall. This was due to a significant mobilization of the soil's shear strength.



(a) End of Construction of the Wall



(b) End of Surcharge Application

Figure 9. Horizontal Stresses *vs.* Depth

Table 2 shows a comparison between Rankine's active and at rest earth loads, and measured earth thrusts. The ratio between the earth thrust measured and Rankine's or at rest earth loads are indicated between brackets. It is observed that the use of a tighter connection between tires does not affect earth load against the wall until the end of construction. With the progress of the load application, due to the placement of the surcharge, the stiffness of the wall plays a more important role. The further load application engages the connection between tires, in the load carrying capacity, more effectively.

Table 2. Comparison of Earth Thrusts

After Construction of the Wall		
Section B	$E_{measured}$	49.kN/m
	E_a	34 kN/m (143%)
	E_o	49 kN/m (100%)
Section C	$E_{measured}$	45 kN/m
	E_a	31 kN/m (145%)
	E_o	44 kN/m (100%)
Section D	$E_{measured}$	46 kN/m
	E_a	35 kN/m (131%)
	E_o	50 kN/m (92%)
After Surchage Aplication		
Section B	$E_{measured}$	64 kN/m
	E_a	101 kN/m (63%)
	E_o	144 kN/m (44%)
Section C	$E_{measured}$	67.0 kN/m
	E_a	92.2 kN/m (73%)
	E_o	131.7 kN/m (51%)
Section D	$E_{measured}$	42.4 kN/m
	E_a	84.0 kN/m (50%)
	E_o	120.0 kN/m (35%)
Notes: E_a = Rankine's Active Trust; E_o= at Rest Trust ; ( ) ratio between $E_{measured}$ and E_o or E_a		

The total earth load for section C, after the surcharge application, was 73% of the assumed Rankine's earth thrust, while in section B it was only 63%. If these results are compared with the measured horizontal displacements, they reinforce the idea that high stress levels produced, in section C, can be attributed to a wall displacement pattern closer a rigid block movement.

Section D, which leaded to stress levels closer to failure, particularly after the surcharge application, produced significant reduction on the earth pressure over the wall.

2.2 Reinforced Retaining Wall Soil reinforcement technique is based on the insertion of elements into the ground, capable of resisting tensile loads. The shear stress developed at the soil-reinforcement interface reduces the horizontal thrust on retaining structures, improving its stability conditions.

Not only the shearing resistance of the soil-reinforcement interface contributes for increasing the stability of the retaining structures, but also 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 experimental program herein described consisted of a series of full-scale pullout tests, in which horizontal loads were applied to a tire mesh, embedded in a sandy backfill material. Figure 10 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 11) has a horizontal steel frame, with a concrete base, anchored in residual soil, by two 15m inclined anchors.

The pullout load was activated by a hydraulic pump (Figure 11), which transmitted pressure to a hydraulic piston, which was positioned at the threaded rod. The horizontal load was transferred to each individual front tire by a chain linked to this rod. A 500kN load cell was used for monitoring applied loads.

The load system ensured no displacement restraints to each individual tire placed at the front row.

To permit displacements greater than the maximum piston travel (180mm), the system had a device which allowed the maintenance of the constant load while the pistons were retreated and relocated prior to further load application. This procedure allowed

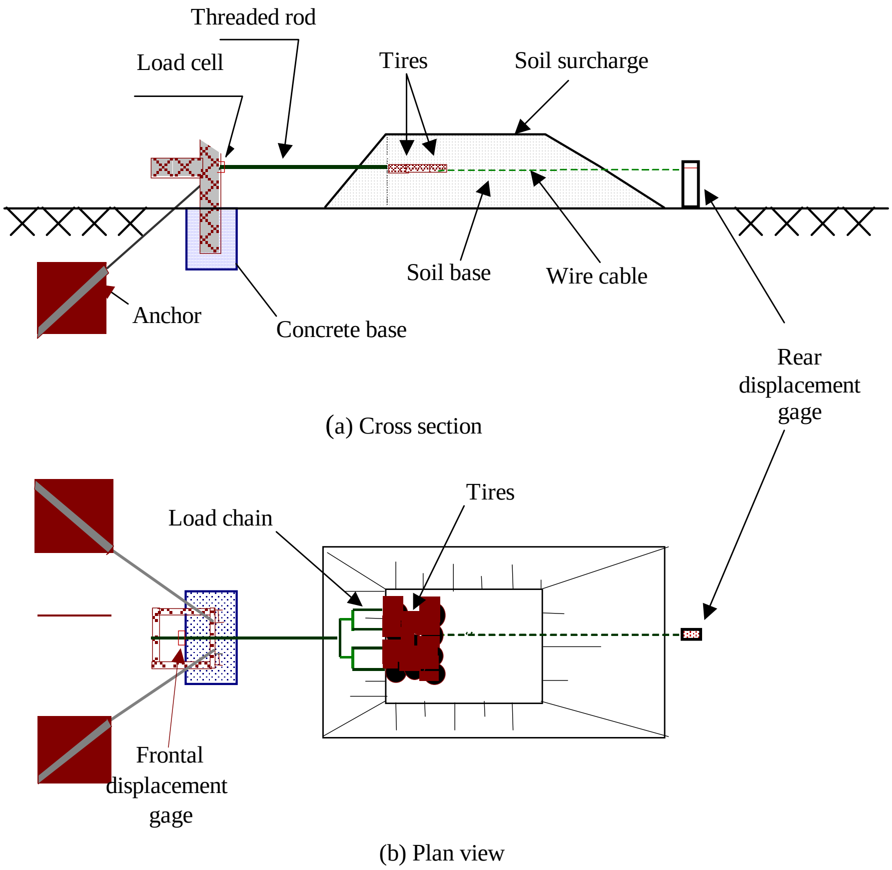


Figure 10. Field Pull-out Tests Scheme

Figure 11. Reaction Structure and Hydraulic Piston

performing tests up to the mobilization of the maximum pull-out resistance of the tire mat.

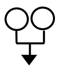
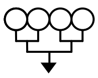
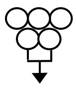
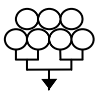
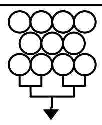
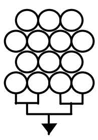
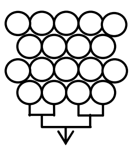
The horizontal pullout displacements were observed, with 0.5 mm accuracy, at different locations: (a) on the threaded rod, corresponding to the displacement of the first row of tires (frontal displacement); (b) on internal positions of the embedded tires (internal displacement). The internal displacements were monitored by horizontal nylon cables tied to the tires that extended outward the soil surcharge.

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.

Field test setup and monitoring details have been presented elsewhere [17, 18].

2.2.1 Testing programs Table 3 summarizes the testing program. In arrangements with more than one tire, two turns of a 6mm thick polypropylene rope were used between adjacent tires.

Table 3. Pullout testing program

Arrangement	Description
	1 Tire
	2 Tires
	4 Tires
	2X3 Tires
	4X3 Tires
	4X3X4 Tires
	4X3X4X3 Tires
	4X5X4X5 Tires

The influence of tire geometry was evaluated by performing tests with full and cut tires.

The soil surcharge ranged from 8 to 42 kPa, corresponding to 0.5m to 2.5m of soil height.

In front of the first row of tires was the soil was kept in loose state, for reducing the soil's passive resistance.

To ensure horizontal leveling, the tire mats were placed over a 0.5m height soil base.

The sandy embankment was manually compacted. Internally, the 0.6m diameter tires were also filled up with compacted soil. In some cases, the soil was mechanically compacted with the use of a bulldozer shovel.

The voids between adjacent tires were also carefully filled with soil.

The significance of the tire filling material was also assessed by having the tires partly filled with a stiff material. This stiff material was either a soil-cement mixture (10% in weight) or an unreinforced concrete slab placed inside of the tire, at its midheight. The thickness of this slab was smaller than the tire height, ensuring that shear mobilization took place along the soil-soil contact.

Figure 12 presents a view of the soil embankment during a pull-out test.

Figure 12. : Pull-out Test View

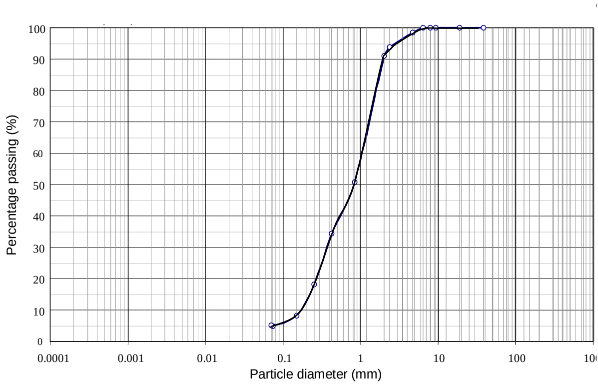


Figure 13. Grain size distribution of sand - Phase 2

2.2.2 Materials

Two materials were used for the construction of the embankments: local soil [17] and a commercially available sandy soil [18].

The geotechnical parameters of local soil are described in Table 1 and these tests will hereafter be designated as Phase 1.

The sandy soil used in the Phase 2 testing program was a well-graded coarse sand (SW), with strength parameters c' = 4,3kPa and ϕ' = 31.7°. Figure 13 shows the grain size distribution and Table 4 summarizes geotechnical characterization of sand.

Table 4. Geotechnical characterization of compacted sand (Phase 2)

Water content (%)	8.3
Specific gravity of solids	2.67
Unit weight (kN/m³)	16.8
Void ratio	0.71
Maximum void ratio	0.80
Minimum void ratio	0.57
Relative density (%)	42

2.2.3. Field Results At the beginning of the tests, the displacements were observed to be primarily due to deformations of the first row of tires. As the test proceeded, deformations of subsequent rows were successively initiated. The initially circular tires were noted to reach an elliptic shape, at the final stages of the tests. As a consequence, non-uniform stresses and strains were generated at the shear interface. Figure 14 shows a view of a 4X3X4 arrangement of tires at the end of a pullout test.

Figure 14. 4X3X4 arrangement at the end of test

The load-displacement curves resulting from pullout tests did not exhibit a marked peak, but the pullout load at failure could be reasonably defined. Figure 15 shows typical results of Phase 2 testing program. Similar results have been observed in Phase 1.

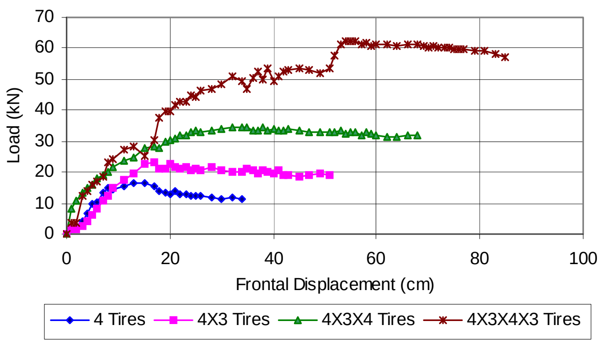


Figure 15. Load vs Displacement - 1m Soil Surcharge (Phase 2)

Table 5 shows a summary of the pullout test results for the different tire arrangements. It is observed that increasing the number of tires caused proportionally larger pullout loads.

Table 5. Pullout test results

Arrangement	H * (m)	P_f ** (kN)	P_f / # Tires (kN)	Δ_f *** (m)
Phase 1				
1 (cut tire)	1.0	5.4	5.4	0.13
1 (full tire)	1.0	6.7	6.7	0.20
2 (cut tire)	1.0	7.1	3.6	0.15
4 (full tire)	1.0	16.3	4.1	0.15
2 X 3 (cut tire)	1.0	21.0	4.2	0.32
4 X 3 (cut tire)	1.0	22.0	3.2	0.20
4 X 3 X 4 (cut tire)	1.0	35.0	3.2	0.34
4 X 3 X 4 X 3 (cut tire)	1.0	62.0	4.4	0.61
4 X 5 X 4 X 5 (cut tire)	1.0	65.0	3.6	0.45
Phase 2				
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	108.94	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

No significant differences have been observed in pullout displacement curves for full and cut tires.

The pullout load normalized behavior with respect to the number of tires is plotted in Figure 16. Each curve refers to specific vertical stress levels and to different types of tires (full 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. Although, one can comfortably assume that these curves converge to higher values.

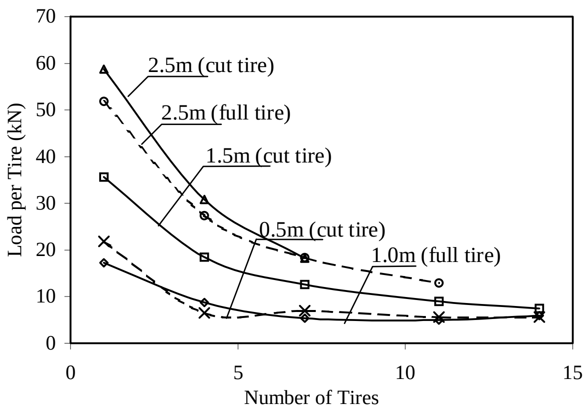


Figure 16. Maximum load normalized behavior. Phase 2

The ratio between the normalized load and surcharge height is shown in Figure 17. With the exception of the tests with 0.5m surcharge height, the pullout load per tire can be represented by a single curve for each testing program.

Tests performed by O'Schaughnessy & Garga [19] are also plotted. The authors 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, pullout tests with a single tire in the first row are disregarded.

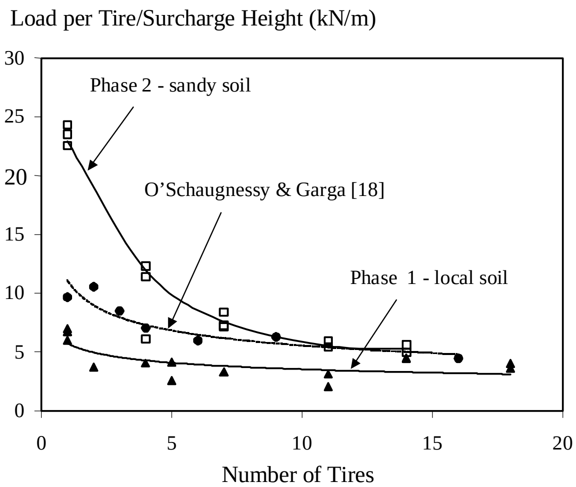


Figure 17. Pullout resistance normalized behavior.

The results apparently indicate that, for tire arrangements with more than 14 tires, the normalized pull-out strength approaches a constant value for all tests, apparently independent of the soil type of the embankment. The small differences between field pull-out tests can be associated to the influence of different grain size distributions and relative densities of the backfill materials. The results also suggest that a minimum pullout tire capacity of 4kN per surcharge height (m) may be used for engineering purposes, whenever normal stresses are kept bellow 42kPa.

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 [15].

Displacements of all tire arrangements have indicated a progressive mobilization of shear strength at successive tire rows.

At the earlier stages of the tests, the displacements were primarily due to deformations of the first row of tires. As the test proceeded, the deformations of the subsequent rows were successively initiated. It was also observed that the rope knots connecting adjacent tires were tightened with the load application, resulting in an unforeseen displacement. These displacements were visually verified after the completion of the tests and ranged between 0.02m to 0.04m (Figure 14). The monitoring procedure did not allow the identification of each component of frontal displacement throughout the test.

Figure 18 shows frontal displacements normalized by number of rows for the different tire mats. 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 arrangements with a greater number of rows, frontal displacement at failure was nearly constant, ranging from 0.07m to 0.20m, per transversal tire row. Due to the limited number of tests the influence of vertical stress level is not conclusive. O'Schaughnessy & Garga [17] results are also plotted in Figure 18. 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.

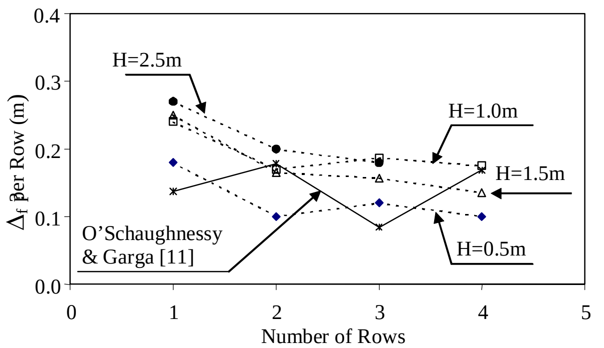
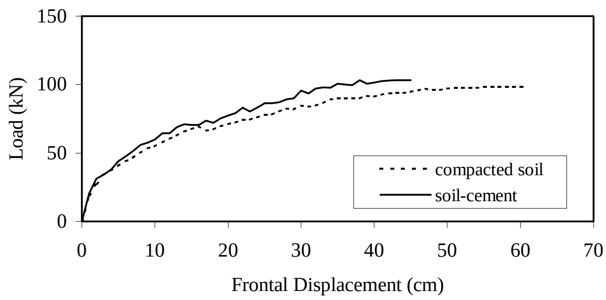


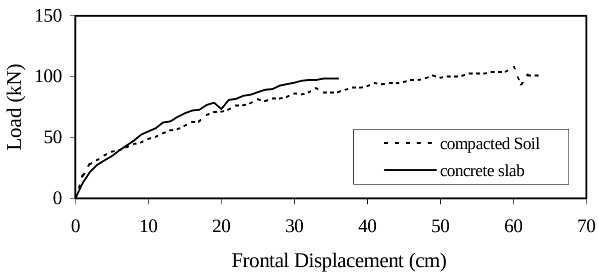
Figure 18. **Frontal displacement normalized behavior, for different surcharge heights (Phase 2).**

Phase 1 testing program, with 1m surcharge height, have shown an increase of 0.12m of frontal displacement, at failure, per each transversal tire row. These results are of the same magnitude of the ones presented in Figure 18 .

The influence of internal tire stiffness was also evaluated by performing pullout tests with tire filled with a soil-cement mixture or unreinforced concrete slab. Field results (Figure 19) indicated that the soil stiffness in the tires did not affect significantly the pullout resistance, but produced a stiffer tire mat. The test performed with a concrete slab indicated a 37% reduction of frontal displacements at failure, while soil-cement mixture caused a slightly reduction of 8.5%.



(a) 4x3x4 tire arrangements



(b) 4x3x4x4 tire arrangements

Figure 19. Influence of tire stiffness.

3. CONCLUSIONS

This paper presented results of a comprehensive research project, developed in Rio de Janeiro, Brazil, on use of scrap tires for Civil Engineering purposes. The field tests have shown that this alternative is a feasible and low cost environmental engineering solution.

Due to tire mechanical properties and construction procedures the results of soil-tire wall instrumentation indicate that the four sections of prototype wall behaved adequately in terms of stresses and deformation even for the narrower section (section D) designed with low safety factor.

The resulting structure is more flexible than the conventional retaining walls, therefore they produce higher horizontal displacements which allow stress relaxation and load transfer. Nevertheless, the observed lateral displacements, for all sections, were kept within reasonable limits.

From the lateral displacement point of view, there is no significant difference between using full tires and cut tires, tied with polypropylene rope. However, it is expected that the vertical displacement in the backfill should be reduced with the use of cut tires. The use of a more restrictive tightening arrangement produces a stiffer wall, and its displacement pattern does not depart significantly from a rigid body movement.

Despite the observed horizontal displacements during construction of the wall, the total lateral load, in all sections, have a magnitude, similar to the at rest condition. This behavior can be attributed to the construction sequence, since both the wall and backfill are built from bottom to top. The most common lateral displacement form observed in gravity retaining walls is either a rotation around the base or a constant horizontal displacement with depth. Both forms do not apply to the present case. The wall does not have a rigid body motion and its flexibility helps the load transfer mechanical action.

Similar to the lateral displacement monitoring, no significant difference between using full tires and cut tires has been noticed on the measured earth pressure values, particularly at the end of wall construction.

The additional load due to the 2m-height surcharge, mobilized an expressive portion of the shear strength of the backfill and increased the importance of the load transfer mechanism.

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 ($\tan\delta/\tan\phi'$) 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 main advantages of using scrap tires in slope stabilization and soil reinforcement projects are:

- The technique requires local soil, scrap tires and rope, with no need of materials such as cement, steel or aggregate.
- There is no need for previous treatment of tires before raising them in the wall or arranging them in the reinforcing system.
- The gravity wall can be constructed with light compaction equipment or even manually.
- Transportation costs are usually low when scrap tire deposits are available in urban areas.
- Tires embedded in earthfills apparently do not affect the quality of groundwater.

4. ACKNOWLEDGEMENTS

The authors are grateful to the financial support of Brazilian Research agencies CNPq and FAPERJ. The authors also acknowledge the financial assistance of IDRC (International Development Research Center, Canada) and GeoRio - Geotechnical Institute Foundation of Rio de Janeiro, Brazil.

5. NOTATION

c'	effective cohesion
ϕ'	effective friction angle
H	wall height
δ	interface friction angle

ν	Poisson’s ratio
Δ_f	Frontal displacement at failure
E_a	Rankine’s active trust
E_o	At rest trust
$E_{measured}$	Measured trust
P_f	Pullout force at failure

REFERENCES

1. O'Schaughnessy, V. & Garga, V.K., *Tire-reinforced Earthfill. Part3:* "Environmental assessment", ***Canadian Geotechnical Journal***, 37, 2000, pp. 117-131.
2. Hausmann, M.R. (1990) - "Slope Remediation". Stability and Performance of Slope and Embankments-II, **Geotechnical Special Publication ASCE** n°. 31, edited by R.B. Seed and R.W. Boulanger, vol. 2, p. 1274-1317.
3. Long, N.T. (1984), "Pneusol, Tyresoil, Tiresoil". Colloque Routes et Development, **Ecole National des Ponts et Chaussées,** France, 17p.
4. Long, N.T. (1990) - "The Pneusol". Publication GT44, Laboratoire Central des Ponts et Chaussées, France, 76p.
5. Sieira, A.C.C.F.; Sayão, A.S.F.J.; Medeiros, L.V. & Gerscovich, D.M.S., "Experimental Soil-tire Retaining Wall", ***Revista Portuguesa de Geotecnia***, no. 91, julho, 2001, 17p. (in Portuguese).
6. Garga, V.K.; Shaughnessy, V.O.; Medeiros, L.V.& Sayão A.S.F.J., "Behavior of Scrap Tire Reinforced Retaining Walls*:* Canadian and Brazilian Experiences", **11th Pan-American Conf. on Soil Mechanics and Geotechnical Engineering**, Foz do Iguaçu, Brasil, vol. 3, 1999, pp. 1199-1206.
7. Garga, V. K. and O'Shaughnessy, V. (1995). Use of Scrap Tires for Embankment Construction. **48th Canadian Geotechnical Conference**, vol. 1, p. 425-432.
8. O'Schaughnessy, V. & Garga, V.K., *Tire-reinforced Earthfill. Part1:* "Construction of a test fill, performance, and retaining wall design", ***Canadian Geotechnical Journal***, 37, 2000, pp. 75-96.
9. O'Schaughnessy, V. & Garga, V.K (2000), *Tire-reinforced Earthfill. Part2:* "Pullout Behavior and Reinforced Slope Design", ***Canadian Geotechnical Journal***, 37, pp. 97-116.
10. Masad, E.; Taha R.; Ho, C. Papagiannakis, T. (1996) Engineering properties of Tire/soil mixtures as a lightweight fill material, ***Geotechnical Testing Journal***,

American Society for Testing material, pp.297-304.

11. Tweedie, J.J.; Humphrey, D.N.; Stanford, T.C. (1998), Tire shreds as lightweight retaining wall backfill: active conditions, ***Journal of Geotechnical and Geoenvironmental Engineering***, pp.1061-1070.
12. Lee, J.H.; Salgado, R.; Bernal, A.; Lovell, C. W. (1999), Shredded tires and rubber-sand as lightweight backfill, ***Journal of Geotechnical and Geoenvironmental Engineering***, pp.132-141.
13. Medeiros, L.V.; Garga, V.; Gerscovich, D.M.S.; Sayão, A.S.F.J. & Andrade, M.H.N., "Analysis of the Instrumentation of an Experimental Scrap Tire Retaining Wall", ***11th Pan-Am. Conf. on Soil Mechanics and Geotechnical Eng***., Foz do Iguaçu, vol I, 1999, pp. 19-25.
14. Medeiros, L. V.; Sayão, A. S. F. J; Garga, V. K & Andrade, M. H. N., "Use of Scrap Tires in Slope Stabilization", ***2nd Pan Am. Symp. on Landslides,*** Rio de Janeiro, vol. 2, 1997, pp. 637-644.
15. Medeiros, L. V.; Sayão, A. S. F. J; Garga, V. K & Andrade, M. H. N., "Use of Scrap Tires in Retaining Walls", ***International Journal of Environmentally Conscious Design and Manufacturing,*** vol 6, 1997, pp. 19-24**.**
16. Jaky, J., "The coefficient of earth pressure at rest, ***Journal of the society of Hungarian Architects and Engineers***, 1944,pp. 355-358.
17. Gerscovich, D.M.S.; Medeiros, L.V. de.; Sayão, A. S. F.J. & Garga, V. K., :"Field Pullout Tests on Scrap Tire Arrangements", ***International Conference on Geotechnical & Geological Engineering***, Melbourne, 2000, CDROM.
18. Gerscovich, D.M.S.; Medeiros, L.V. de.; Sayão & A. S. F, "Field Pullout Tests of Scrap Tire Reinforcement Layers under Different Soil Surcharges", ***XV International Congress on Soil Mechanics and Geotechnical Engineering***, Istambul, 2001.
19. O'Schaughnessy, V. & Garga, V.K., *Tire-reinforced Earthfill. Part2:* "Pullout Behavior and Reinforced Slope Design",

Canadian Geotechnical Journal, 37,

2000, pp. 97-116.