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Analysis of the Instrumentation of a Scrap Tire Reinforced Retaining Wall

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ABSTRACT: A comprehensive research project on tire waste utilization as a low cost alternative for slope stabilization, has been carried out. A prototype earth retaining wall, 4 meters high by 60 meters long, was constructed with an additional placement of a surcharge load of 2 meters of soil on the backfill. To examine different cross sectional configurations, the wall was comprised of four sections with different combinations of entire/cut tires, tied with polypropylene rope/plastic coated wire. All sections were fully instrumented with deep inclinometers tubing, magnetic extensometers and earth pressure cells. This paper describes the construction of the and analyses its behavior based on field instrumentation. The results indicate lateral movements higher than conventional concrete retaining walls and relatively small values of active earth trust, due to arching effects.

KEYWORDS: Reinforced Retaining Wall, Scrap Tires, Slope Stabilization, Field Instrumentation

1 INTRODUCTION

Industrial societies produce scrap tires at increasing rates every year, and presently this waste disposal assumes impressive quantities. In 1995, the world tire production was 800 million; Brazil produces annually 33 million tires (Mousinho, 1997). It is estimated that there are approximately 3 billion used tires 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 landfill sites is limited.

Scrap tires are usually disposed in stockpiles or land fills. In both cases, these deposits are exposed to constant danger of fire and also induce propagation of vermin and insects, particularly important in tropical environment with poor sanitation conditions. It is highly likely that the Aedes Albopicus mosquito which transmits dengue fever was introduced to Brazil through imported scrap tires (CEMPRE, 1994). This type of mosquito eggs easily adheres to internal tire walls and produces larvae. The accumulation of moisture in scrap tires in combination with heat and dark environment provides an excellent environment for breeding of vermin.

The options for an environmentally acceptable management include the following:

- Reduction as a consequence of a technological development that improves service life,
- Re-use as tires by retreading,
- Recycle by cutting, to make new products such as floor mats,
- Recycle by grinding, to make asphalt mixtures or rubber plastic compounds,
- Recycle of tire chips in applications such as road beds and tracking fields,
- Recover of the raw material to manufacture new products,
- Process of the tire to make tire-derived fuel,
- Re-use of the whole tire for Civil Engineering purposes.

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

Considering the frequent use of steel meshes imbedded in the latex in manufacturing modern tires, a significant portion of the above applications can not utilize such tires, therefore reducing the reutilization of an expressive number of scrap tires. Processing used tires requires a significant investment as well as strict control on air emission. The percentage of tire reutilization varies according to the industrial setting of each region, being presently limited to a range of 15% to 45%. The present contribution is devoted to the re-use of the whole tire to build reinforced retaining walls.

This paper reports the results of a research project, which intends to promote an efficient engineering application of used tires, consequently reducing the potential hazard to the environment.

2 SCRAP TIRE REINFORCED 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. If tires are filled with soil placed side by side, in successive layers, and tied together to make a mat or a chain, the resulting material can be used as a low cost gravity retaining wall (Long, 1990).

If the tires are cut to remove one sidewall, the placement of soil in the tires is facilitated and a higher degree of compaction is therefore obtained. Since nearly all tires are nowadays reinforced predominantly with steel, the tire cutter blade must be able to slice the tire reinforcement without loosing its cutting capacity.

Construction of retaining walls with tires requires light equipment only; therefore this technique can be easily adapted to local practice. Since, in a gravity retaining wall, the role of the soil is primarily to provide the weight; soils with poor geotechnical characteristics may also be used in the construction of the wall.

The use of soils locally available at the construction site will usually satisfy design specifications with a significant reduction in construction costs. The filling of the tire with soil can be accomplished even by manual compaction. This type of wall does not require cement or steel.

In addition, transportation costs are usually not very high in metropolitan areas, where scrap tire deposits are easily found.

This retaining wall absorbs strains without cracking therefore allowing redistribution of the earth pressure along the face of the wall. This feature is convenient in non-urbanized areas where deformations in the backfill may not be a serious consideration. Such structure provides a useful destination for scrap tires.

Other geotechnical applications using scrap tires have described elsewhere (Garga & O'Shaughnessy, 1995).

3 CONSTRUCTION

To investigate the application of tires as soil reinforcement in retaining walls; a retaining wall, 60 meters in length and 4 meters in height was built. An additional surcharge load of 2 meters of soil was placed after the completion of the wall. Details of the construction and monitoring of the wall have been presented elsewhere (Andrade et al, 1997; Medeiros et al, 1997a; Medeiros et al, 1997b).

In order to increase the density of the retaining wall, one tire sidewall can be removed. For the present research, a specially designed tire slicing machine was used, with a cutting rate capacity of over 100 tires per hour. The use of tires with one removed sidewall produces a wall with higher specific weight and lower compressibility. Cut tires are of particular importance if clayey soil is selected for building the wall.

The reinforced wall was comprised of four different sections, as shown in Figure 1, with the following characteristics:

- *Section A*: Wall made of entire tires tied with a 6mm thick polypropylene rope having a width of six tires at the base and four tires at the top
- *Section B*: Wall made of cut tires (one sidewall removed) with the same cross section and rope connection as in section A.
- *Section C*: Wall made of cut tires with the same cross section in section A, but tied with a plastic coated galvanized zinc wire of 2mm in diameter.
- *Section D*: Wall made of cut tires with polypropylene rope, but with a uniform width of three tires only.

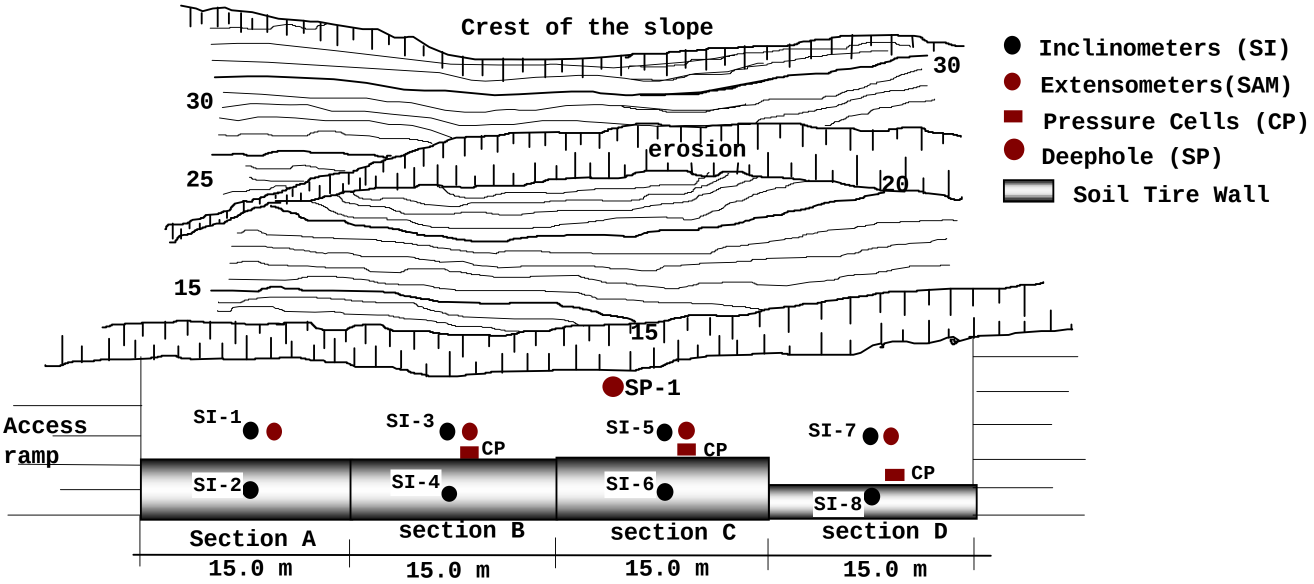


Figure 1. Site Plan and Instrumentation Location

The retaining structure was built in the following sequence:

- The base surface was cleaned and leveled.
- The first layer of tires was placed with the natural water content in an orthorhombic arrangement.
- The tires were tied together. The front row of tires for each of the sections was tied together by two turns of the rope or one turn of the wire. The remaining tires were tied to adjacent four tires by a single turn to form the tire mesh.
- There was no connection between tires of different layers of tire meshes.
- Soil compaction was done using manual labor and light machinery.
- Successive layers of tires and soil were placed with the center of the tires laterally displaced (30cm) in relation to the layer below to promote the interlocking of the layers.
- To guarantee the designed geometry the first row of tires was placed 2 to 3 cm towards the backfill to account for the deformation and displacement of the tires during compaction of the soil inside the tires and the backfill soil. It is important to avoid overhanging tires on the external surface.
- To provide a uniform arrangement only car passenger tires were utilized; they have 0.60m of external diameter, 0.30m of internal diameter and 0.20m of thickness.

The construction has progressed satisfactorily although some delays occurred due to periods of intensive rain. The soil fill was obtained from a local borrow pit. The characterization of this soil and its mechanical properties after compaction were obtained in the laboratory and through a series of in-situ tests (Fontes, 1997).

4 INSTRUMENTATION

The horizontal movement of the wall, as well as the backfill, was monitored in vertical holes with eight 13m deep inclinometers tubing, four inside each section and four inside the backfill of each section immediately behind the retaining wall. Vertical movement in depth was registered with magnetic extensometers installed in the backfill. The earth pressure against the retaining wall was monitored with nine pneumatic earth pressure cells (Figure 2).

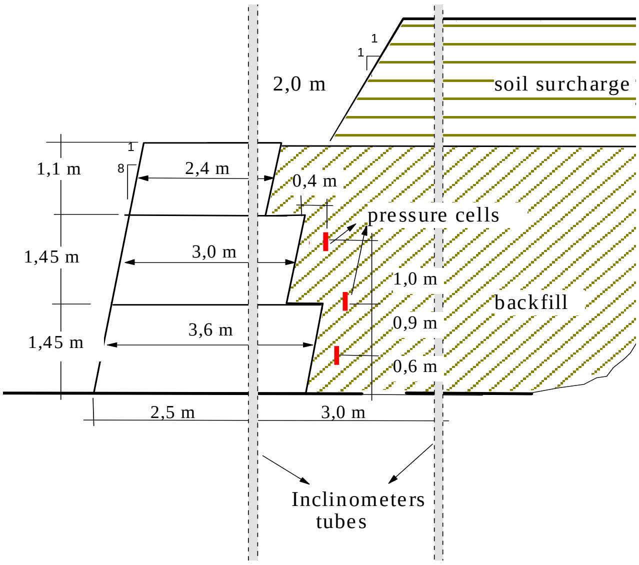


Figure 2. Typical Cross Section and Field Instrumentation

In order to evaluate soil-tire iteration mechanism, a series of full scale pull out tensile tests with different tire arrangements have also be performed. (Medeiros et al, 1997c).

Numerical simulation of the wall construction sequence and its comparison with field results has been presented elsewhere (Sieira, 1998).

4.1 Materials

4.1.1 Retaining wall

The stability of such wall is a function of the specific weight of the soil tire mass which is dependent on the type of tire to be used; the use of tires with sidewall removed result in denser soil tire mass when compared with entire tires. A series of density tests was performed in a concrete lined pit for evaluating the specific gravity of different soil-tires configurations. This pit accommodates three layers of nine tires each (Figure 3). The field construction procedure was reproduced inside the pit, with entire and cut tires. Two different well graded soils, a silty sand and a coarse sand, were used as filling materials. The silty sand was also used as the wall backfill material.

Figure 3. Field Density Tests

For engineering purpose, no differences were observed between the specific weight of the retaining wall built with these two soils. The values of specific weight observed in the test pit were respectively 16.2kN/m^3 and 16.5kN/m^3, for cut tires, and 15.4kN/m^3 and 15.6kN/m^3, for entire tires. It was therefore observed a reduction of about 6% 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 entire tires, the observed reduction was 11%. This reduction in specific weight has to be considered in designing such structures.

4.1.2 Backfill

The soil at the experimental site is a well graded clayey silty-sand (Unified Soil Classification: SC), weathered from a gnaisssic rock mass. The natural water content ranges from 15% to 20% and the Atterberg limits are 36% (Liquid Limit) and 23% (Plastic Limit). The specific weight of backfill compacted soil is about 17.5 kN/m^3.

Drained triaxial tests and direct shear tests were performed block samples extracted in the backfill at 2.5m depth. Conventional triaxial tests were carried out with confining stresses ranging from 50kPa to 150kPa and have indicated a friction angle of 29^o (Fontes, 1997).

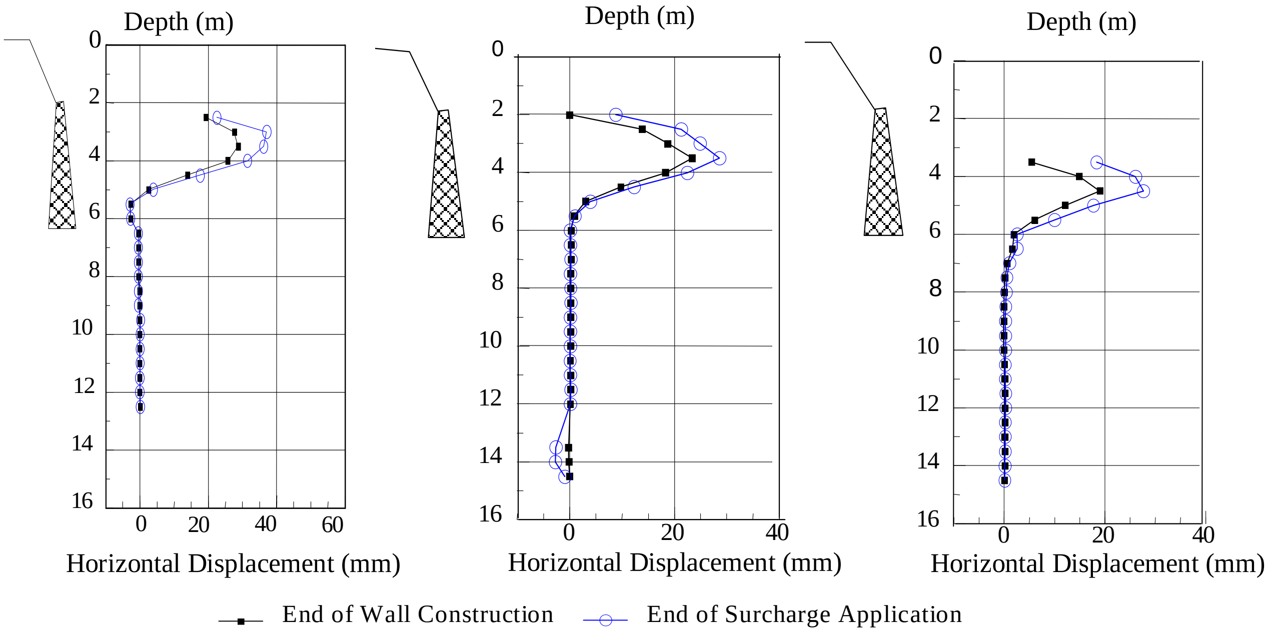
4.2 Field Results and Analysis

4.2.1 Horizontal Displacements

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

The horizontal movements were monitored throughout the construction and after the placement of the surcharge. Figure 3 presents the horizontal displacements in wall sections B, C and D, at the end of wall construction and at the end of surcharge application. Considering the construction sequence of both backfill and wall, with filling from bottom to top, the horizontal displacement monitoring initiates earlier at the bottom layers. This construction and monitoring sequence contributes to displacement profile patterns significantly different from the ones commonly observed during construction of unbraced sheet pile walls, which are previously placed in the ground before soil excavation.

In all sections, it was observed that the maximum horizontal displacement occurred within the middle third of the wall height. For concrete retaining walls, the maximum horizontal displacement is expected to have a value between 0.2% to 0.4% of the wall height for similar backfill soils.



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

Figure 4. Horizontal Displacements at the End of Construction and End of Surcharge

Section A, which was built with entire tires and polypropylene rope, resulted in a slightly lighter wall and therefore in a slightly more flexible wall than sections B and C. At the end of construction, the maximum horizontal displacement in section A was 28mm. This corresponds to 0.7% of the wall height. The maximum horizontal displacement of section C, which was the least flexible was 20mm, at the end of construction. This corresponds to 0.5% of the wall height. Retaining walls built with soil and tires therefore show a higher flexibility than conventional gravity walls. 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.

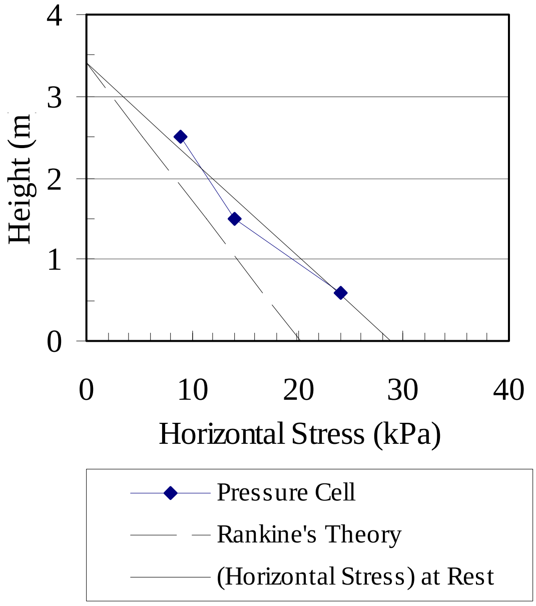
It is interesting to note that the application of the surcharge in section A, produced additional lateral displacement concentrated near the zone of the maximum horizontal displacement, indicating some bulging around the middle of the height. This feature suggests the existence of a relative movement between the tires in the middle, and the tires near the top and the bottom of the wall. This behavior is significantly different form 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.

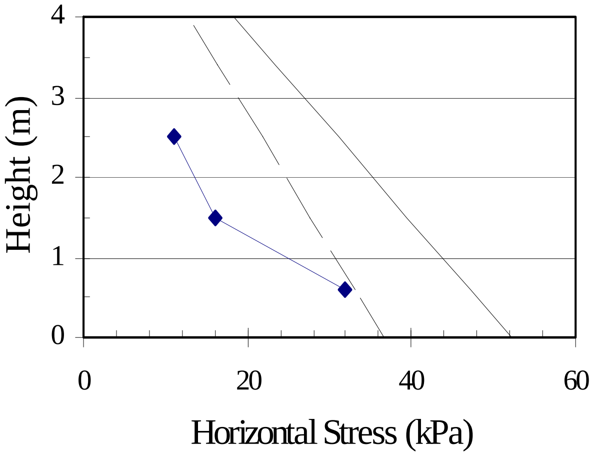
4.2.2 Earth Thrust

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.

Earth pressure readings in section B, at the end of construction and surcharge application, are presented in Figure 5. These results, which have a similar pattern to the ones in sections C, are compared with Rankine's earth pressure distribution. Despite the observed horizontal displacements during construction of the retaining wall, the measured horizontal stresses at the end of the construction do not depart significantly from the at rest state of stress condition based on laboratory shear strength results. At the end of construction of the wall, the horizontal stresses in the middle earth pressure cells, approached the Rankine's active earth pressure. This observation, in connection with the lateral displacement readings, indicates that the flexibility of the wall promotes an expressive load transfer from the soil located in the middle part of the backfill to both edges.



(a) End of Construction of the Wall



(b) End of Surcharge Application

Figure 5. Distribution of Predicted and Measured Horizontal Stresses

After surcharge application, there was a significant mobilization of shear strength of the soil (Figure 5b). This behavior resulted in stresses below Rankine's theory for the first three meters of the wall. The retaining wall near the base had little movement with the application of the surcharge which resulted in stress concentration around this area.

Table 1 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. 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.

Table 1 - Comparison of Earth Thrusts

	After Construction of the Wall		After Surchage Aplication	
Section B	$E_{measured}$	49.kN/m	$E_{measured}$	64 kN/m
	E_a	34 kN/m (143%)	E_a	101 kN/m (63%)
	E_o	49 kN/m (100%)	E_o	144 kN/m (44%)
Section C	$E_{measured}$	45 kN/m	$E_{measured}$	67.0 kN/m
	E_a	31 kN/m (145%)	E_a	92.2 kN/m (73%)
	E_o	44 kN/m (100%)	E_o	131.7 kN/m (51%)
Section D	$E_{measured}$	46 kN/m	$E_{measured}$	42.4 kN/m
	E_a	35 kN/m (131%)	E_a	84.0 kN/m (50%)
	E_o	50 kN/m (92%)	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

5 CONCLUSIONS

The use of scrap tires is a feasible environmental solution for building earth retaining walls at low cost.

The results of field instrumentation indicate that the four sections of prototype tire wall behaved adequately in terms of stresses and deformation even for the section 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 entire 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 entire 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 surcharge, mobilized an expressive portion of the shear strength of the backfill and increased the importance of the load transfer mechanism.

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