Geotextiles and Geomembranes 44 (2016) 201–208

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Study of a small scale tyre-reinforced embankment

Lihua Li [a, b], Henglin Xiao [a], Pedro Ferreira [b, *], Xilin Cui [a]

[a] School of Civil Engineering and Architecture, Hubei University of Technology, Wuhan, 430068, China
[b] Department of Civil, Environmental and Geomatic Engineering, University College London – UCL, Gower Street, WC1E 6BT, London, UK

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form
27 August 2015
Accepted 29 August 2015
Available online 28 September 2015

Keywords:
Geosynthetics
Waste tyres
Soil reinforcement
Stress
Settlement
Model test

ABSTRACT

Tyre-reinforced soil, used to improve slope stability, retaining walls, etc., has an excellent mechanical performance, and has the capability of a wider application and of reducing waste disposal costs. This article studies the stress and deformation characteristics, as well as the influencing factors related to the reinforcing arrangement, through small scale model embankment tests. It is shown that tyre reinforcement highly improved the strength of the model embankments; much higher stresses were mobilised inside the soil mass (around 2 times higher in comparison with the unreinforced embankment). There is an obvious plastic flow in the unreinforced embankment, while the plastic zone, on the reinforced embankments, was difficult to determine. Comparisons between the vertical settlement of the embankments show that the settlement of the reinforced embankment is roughly half of the settlement of the unreinforced embankment, for the same vertical load applied. These results also show that the tests with the top layer of reinforcement nearer the load application area and a smaller distance between the intermediate layers have a better performance, particularly in dense fabrics. The location of the top reinforcement layer seems to dominate the failure modes of the reinforced and unreinforced embankments, the horizontal deformations and the location of the shear bands in the embankment.

1. Introduction

The number of waste tyres around the world has been increasing rapidly in recent years and has become an urgent and serious environmental and economic problem (Hassine et al., 2005; Long, 1996; Bosscher et al., 1997). Waste tyres can be used as reinforcement in the field of geotechnical engineering, and have been regarded as an ideal option (Donald et al., 2008; Huat et al., 2008) to strengthen slopes, retaining walls, embankments, foundations, abutments and, more recently, docks. Waste tyres are normally tied together to either form discrete reinforcement layers within the soil or to provide better stability to the façade of retaining structures. They can also be shredded, mixed into the soil mass and compacted, forming a uniformly reinforced layer; this application, however, requires extra energy and it is less environmentally friendly than using unprocessed waste tyres.

A structure reinforced by tyres usually has the advantages of better seismic performance and durability, low cost, and, although more labour intensive, a simpler construction process. Therefore, it is believed that tyre-reinforced soil will have a wider application in the future, particularly in countries where labour costs are low and mechanisation is not widespread.

The first application of tyre-reinforced soil can be traced back to 1984, where a 5 m high 10 m long retaining wall, was reinforced in France. In the 1990's, another retaining wall, 4 m high and 60 m long, in Brazil, was also reinforced using tyres (Sayão et al., 2009). The results of the tests performed on both structures have confirmed the suitability of tyres to be used as reinforcement in slopes or retaining walls. Other applications have been trialled in many other countries, mainly in slope reinforcement and retaining walls (Garga and O'Shaughnessy, 2007).

The literature on tyre reinforcement has shown that the ultimate pull-out capacity of a waste tyre is 1.25 times that of a geocell or similar reinforcing material (Kim et al., 2011). In addition, the effect of reinforcement has also been found to be significant when applied to a sand foundation (Yoon et al., 2004, 2008). In spite of the current use of tyres as reinforcement, there is insufficient understanding of the mechanism of waste tyres in a reinforced soil, which restricts further applications. Therefore, tests on a small scale model embankment, presented in this article, were carried out to investigate the mechanical performance of a tyre-reinforced sand embankment, including stress-strain characteristics and

---

* Corresponding author. Tel.: +44 (0) 20 7679 4366; fax: +44 (0) 20 7380 0986.
E-mail address: p.ferreira@ucl.ac.uk (P. Ferreira).

http://dx.doi.org/10.1016/j.geotexmem.2015.08.004

failure mode. In this study, the effects of soil density and reinforcing arrangement were also considered.

2. Materials, methodology, instrumentation and test procedure

Tyre reinforced model embankments with a slope ratio of 1:1.3 and a final height of 0.65 m were prepared and tested, in an effort to study the stress and deformation characteristics of different combinations of initial density and reinforcement arrangement. For the embankment, a medium size quartzitic sand was used as the filling material, with a D50 of 0.28 mm and a Cu of 5.3.

All the model embankments were reinforced with small waste tyres from electromobile vehicles having a diameter of 25.4 cm and a height of 9 cm. Each embankment was built using 3 layers of tyre reinforcement, where the tyres on each layer were tied together using a metal wire. In total 10 model embankments were created using 2 different relative densities and combinations between the distance from the top tyre layer and the upper embankment surface, (a), and the vertical distance between adjacent tyre layers, (b). Fig. 1 shows a sketch of the embankment, while Table 1 indicates the initial configuration of each embankment tested.

All model embankments were prepared within a purposely designed steel box of 2000 × 800 × 760 mm, with one 12 mm armour-plated side glass panel. To create the embankments, the sand was compacted in 100 mm layers, using a constant weight hammer, dropping from a constant height. The required relative density was achieved by controlling the energy applied to each layer, until the reinforcement level was reached. The necessary number of tyres for each reinforcement layer were put in place and tied together, with more sand being compacted in between the reinforcement. This procedure was followed until the final height of the embankment was achieved.

To measure the embankment deformation, face markers were installed on the slope surface behind the glass panel, these were monitored using photogrammetry. A set of pressure cells were installed, inside of the embankment, to measure vertical stresses in between soil layers (cells number T1, T3, T4, T7 and T8), and inside the tyre layers (cells number T2, T5, T6, T9 and T10). Fig. 1 shows the arrangement of the instrumentation in the embankment, it is important to point out that not all pressure cells were installed at a given test.

An 800 mm long, 400 mm wide and 40 mm thick loading plate with a hydraulic jack was used to load the top surface of the embankment in increments of 0.5 MPa of hydraulic pressure, followed by a resting period at constant load of 5 min, during which all sensors were logged. A test would be ended when either of the following conditions was observed: (1) a shear surface (crack) appeared along the slope surface, together with a sharp increase of the lateral displacement, or (2) a sudden increase on the vertical settlement occurred, together with a sudden reduction on the vertical applied load.

3. Test results

3.1. Effect of tyre reinforcement on stress

All the reinforced embankment tests performed showed similar behaviour and test A3 was selected as representative, therefore Fig. 2 only shows the variation of pressure, measured by the pressure cells located underneath the loading application area, on tests A3 (reinforced) and A5 (unreinforced). The vertical stress, measured on the unreinforced embankment A5 (Fig. 2b), show an abrupt reduction in all monitored points after failure. As expected, the highest vertical pressure measured is located on pressure cell T2, with the other pressure cells measuring lower vertical stresses; generally the deeper the pressure cell, the lower the vertical stress measured, this was also true for the B tests.

A comparison between the stresses measured on pressure cell T2 and T4, in all A tests (Fig. 3), has shown that the depth of the first reinforcement layer does seem to affect the stresses measured, however, the reinforcement layer allows the soil to reach stresses that are slightly higher than the stresses reached by the unreinforced embankment, for the same loading stage. Furthermore, the extra lateral strength, given by the reinforcement layers, allows the soil to reach vertical stresses that are 2 times higher than the maximum stresses achieved by the unreinforced embankment. Pressure cell T4, located below the first reinforcement layer show similar pressure values to tests A1 and A2 and these are lower than the stresses mobilised by the unreinforced embankment, for the same pressure stage (Fig. 3). Similar results can be observed on tests A3 and A4 (Fig. 3b). The results suggest that the reinforcement layers have a great impact on the transmission of stresses in the embankment, showing how effective a reinforcement layer is in confining the unreinforced layers above, allowing a much greater vertical stress to develop within the top layers and reducing the vertical stresses transmitted to the layers below.

3.2. Effect of tyre reinforcement on settlement

During the test procedure, settlements were measured immediately under the central axis and at the slope surface, these were plotted against the hydraulic vertical pressure applied and are shown on Figs. 4 and 5. The results show that the reinforcement plays an important role in reducing the amount of vertical settlement in all test conditions; the settlement measured on the reinforced embankments is roughly half of the settlement of the unreinforced embankment. Also, the settlement values measured

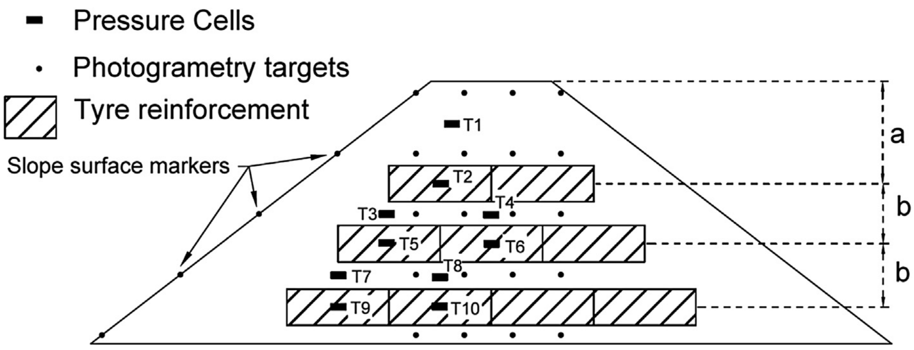

Fig. 1. Elevation profile with the details of the reinforcement layouts tested and the location of the instrumentation.