Use of tire derived aggregate in landfill's drainage systems

O. Garcia
Iberinsa

T. Mateos
Iberinsa, UPM

ABSTRACT

Studies conducted in the United States of America about the geotechnical properties of Tire Derived Aggregate (TDA) have shown that they represent a good option as light weight fill for civil construction due to their technical, environmental and economic advantages. Particularly, stand out their low density and high hydraulic conductivity, without losing the basic requirements as regards bearing capacity and strength, in comparison with standard soils (sand, gravel, etc.). These advantages make TDA especially suitable for their use in landfill's drainage systems.

This paper includes a bibliographic compilation about this application. A state of the art has been completed after geotechnical laboratory essays and the design of big scale pilot tests. Some aspects regarded to the design such as deformability, lixiviate generation and clogging of the drainage system filled with TDA are shown, as well as the preliminary calculations of its long term performance.

Monitoring of the big scale pilot test will reveal details concerning design and construction parameters as regards this type of public works, resulting in the adaptation to the Spanish and European regulations of this technology.

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Keywords: tires, landfill, drainage systems

1 INTRODUCTION

Applications of the Tire Derived Aggregate (TDA) have become recently very attractive for civil construction due to their economical, environmental and technical advantages. This study is focused in their geotechnical advantages, especially their high hydraulic conductivity, which makes them particularly suitable for their use as drainage granular material within landfills drainage systems.

Several research projects regarded to TDA drainage properties have been developed in Europe and U.S.A., with the aim of reducing the landfill construction costs, especially in which concern to soils and groundwater protection. In particular, studies conducted by Humphrey, et al. (2003) and Jesionek, et al. (1998) concluded that due to the high hydraulic conductivity that TDA have shown in their experiments, they might be suitable for their use in landfills drainage systems.

In order to develop this technology in agreement with the Spanish regulations, bibliographic and laboratory research have been made, concluding with the design of a large scale prototype, which will simulate the actions occurring in a landfill leachate drainage layer. The prototype will reproduce the evolution of a landfill drainage system across its service life taking in consideration the possible worse circumstances and using very valuable information acquired from relative projects about TDA mechanical behavior, carried out by this research team (Mateos et al., 2008)

2 PREVIOUS RESEARCH ABOUT TDA HYDRAULIC CONDUCTIVITY

Hydraulic conductivity can be defined as a unit hydraulic gradient water flux under laminar conditions through a cross-plane unit area of a porous media at a standard temperature conditions. In the past, several investigations aimed to accurately measure the hydraulic conductivity of TDA using laboratory equipment (permeameters) with a diameter range from 200 to 1000mm. Some of these permeameters even had the possibility of vertical load application in order to simulate a compression situation as it happens in landfills drainage systems due to the waste weight.

A compilation of TDA hydraulic conductivity values have been made in order to analyze their drainage properties. However, data scattering have been found. This scattering phenomenon may be held to the different experimental conditions applied by the different authors in their experiments (permeameter diameter, vertical stress, particle size and composition, liquid condition).

Figure 1 shows the gathered data, in which the values of hydraulic conductivity for the most desirable cases in each experiment (i.e.: the highest values for the lowest vertical load conditions) are plotted versus the average particle-size used in each case (modified from Reddy et al. 2001). As it can been observed, the range of the hydraulic conductivity values goes from $2x10^{-5}$m/s to $6x10^{-1}$m/s for the different experimental conditions. A boundary criterion was applied, dividing the plot in values below $1x10^{-2}$m/s (non-suitable) and values above $1x10^{-2}$m/s (suitable), since this value is considered, in practice, the lowest hydraulic conductivity for gravels in landfill applications.

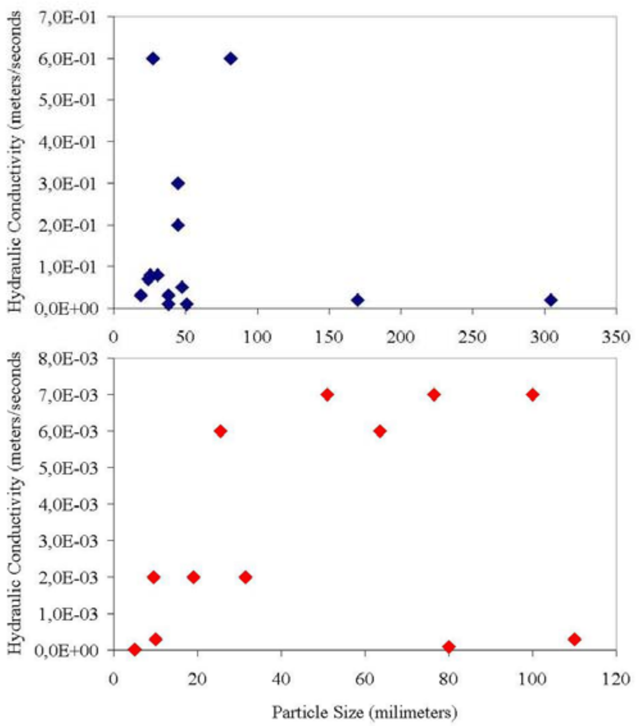

Figure 1.Bibliographic compilation of TDA hydraulic conductivity experimental measurements made since 1984 until 2007. Suitable values (blue). Non-suitable values (red)

It is obvious the conclusion that, under some circumstances, TDA might not be suitable for landfill's drainage layer if simple design criteria are taking in consideration. These unwanted technical conditions appear to be more likely to happen for the leachate drainage layer, due to their extreme conditions of vertical load and clogging susceptibility.

Despite these results, it is important to point out that, in the case of the non-suitable values, most of them were obtained in the laboratory under unreal conditions such excessive vertical load or particle-sizes in discordance with the ASTM D6270. Also, taking a single hydraulic conductivity (for example $1x10^{-2}$m/s) as a boundary design value, may be a too simple criterion whether it is taken in consideration, the important changes experimented by a TDA fill caused by their high compressibility, which provides to the TDA layer a time-variable hydraulic conductivity while is loaded.

3 LABORATORY TEST

In order to develop the drainage layer design for the prototype, it was necessary to determine the variation of the TDA hydraulic conductivity due to the pore space reduction, mainly caused by the vertical load. Oedometric laboratory tests were conducted by the Polytechnic University of Catalonia (Arroyo, 2007) and the CEDEX Laboratory of Geotechnics (Estaire, 2007), in 0,03m^3 and 1m^3 boxes respectively.

The results of these experiments confirmed that for a vertical load up to 150kPa, the volume of empty space in the TDA fill can be reduced up to a 50% of its initial condition (at 0kPa of vertical load). Tests also revealed very low values of the oedometric module as it was expected, according to the TDA characteristics and similar to soft soils values.

On the other hand, the Polytechnic University of Catalonia provided TDA hydraulic conductivity values concerning to their preliminary test results that were performed in an adapted oedometric cell. This cell was able to measure the vertical hydraulic conductivity while applying vertical load to the TDA fill. Even though, the nominal particle-size used in the experiment (7mm nominal size) was wide shorter that the one used on field applications. The resulted data was good enough to establish an empirical mathematical expression that shows TDA hydraulic conductivity variations (in mm/sec) with porosity changes due to different load conditions (Equation 1, Romero et al., 2008).

$$k_w = 1390 \cdot n^6 \tag{1}$$

The empirical expression was used for the calculations in the model proposed in this article.

4 DESIGN MODEL

Nowadays, the design of landfill's drainage systems involves several parameters which are logically connected to the hydraulic conductivity of the porous media. Nevertheless, international regulations and, in particular, European and Spanish regulations, have established limits to the leachate hydraulic head on the primary liner, instead of a hydraulic conductivity value which contributes partially to the correct performance of the liquid drainage layer. However, guidance manuals about TDA uses in landfills, recommends a minimum hydraulic conductivity of $1x10^{-3}$m/s.

Based on regulatory requirements (EU, 1999 and Ley10/1998) the maximum leachate head on the primary liner (Y_{max}) must be less than 300mm. In that sense, different empirical design models have been exclusively developed for this purpose during the last years. The models predict the long term service endurance of the drainage capacity, using several parameters such as the landfill area, steep angles of the drainage layer, drainage pipes characteristics, liquid (leachate) influx and, of course, the hydraulic conductivity of the drainage fill material.

In particular, Qian et al. (2002), recommends the McEnroe's graphic method as the most effective one for the prediction calculations. Based on the standard Dupuit assumptions, McEnroe presented a graphic method in 1989 to estimate the maximum leachate head over the liner. It is only suitable for slopes of less than 10%. McEnroe presented another set of formulas for estimating the maximum saturated depth over a sloping liner in 1993. In the derivation of theses formulas, the lateral drainage over the liner was described by an extended form of the Dupuit discharge formula.

According to McEnroe, the explicit formulas for estimating the maximum liquid head over a landfill liner that is draining freely, with no backwater effect from the collection trough, are expressed as

$$R = r / (k \cdot \sin^2\alpha) \quad (2)$$

$$A = (1-4 \cdot R)^{1/2} \quad (3)$$

$$B = (4 \cdot R-1)^{1/2} \quad (4)$$

If R<1/4 (Figure 2),

$$Y_{max}=L \cdot S \cdot (R-R \cdot S+R^2 \cdot S^2)^{1/2} \cdot \{[(1–A-2 \cdot R)(1+A-2 \cdot R \cdot S)]/[(1+A-2 \cdot R)(1-A-2 \cdot R \cdot S)]\}^{1/(2 \cdot A)} \quad (5)$$

If R=1/4 (Figure 2),

$$Y_{max}=L \cdot S \cdot R \cdot (1-2 \cdot R \cdot S)/(1-2 \cdot R) \cdot \exp\{2 \cdot R \cdot (S-1)/[(1-2 \cdot R \cdot S)(1-2 \cdot R)]\} \quad (6)$$

If R>1/4 (Figure 2),

$$Y_{max}=L \cdot S \cdot (R-R \cdot S+R^2 \cdot S^2)^{1/2} \cdot \exp\{(1/B) \cdot \tan^{-1}[2 \cdot R \cdot S-1)/B]-(1/B)\tan-1[(2 \cdot R-1)/B]\} \quad (7)$$

where Y_{max}: maximum liquid head on the landfill liner, in. or mm; L: horizontal drainage distance, in. or mm; r: inflow rate, in./day or cm/sec; k: hydraulic conductivity of the drainage layer, in./day or mm/sec; S: slope of the drainage layer, S=tan α; and α: slope angle of drainage layer, measured from horizontal, degrees.

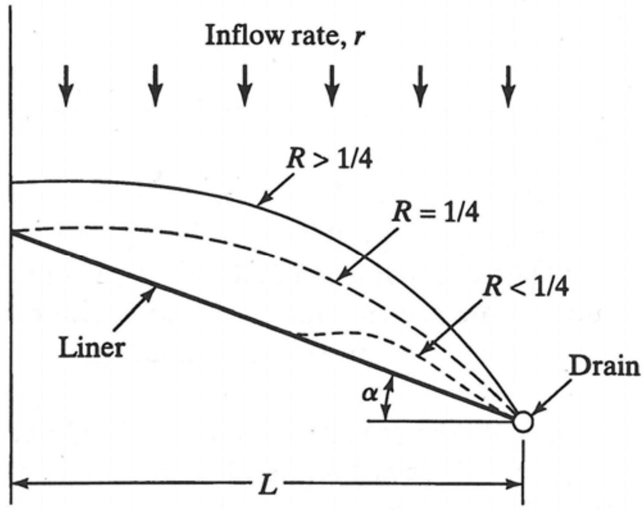

Figure 2.Phreatic surfaces for different R-values.

If the drainage system is working properly, i.e. not excessively clogged, the liquid level in the drainage trench will be bellow the upper edge of the trench, and will have no effect on the saturated-depth profile over the liner. This has been termed the "free drainage condition". In addition, it is recommended a minimum slope of the leachate collection pipe of 1%, and a minimum bottom liner grade perpendicular to the leachate collection pipe of 2%.

Another issue included in this study is the clogging mechanisms: 1) mechanical clogging, 2) biological clogging, and 3) chemical clogging. Even though, the three of them affect traditional fill materials such gravel, laboratory tests conducted by Rowe et al. (2005) showed an increased influence on TDA fills, especially of the chemical clogging. In that sense, controlled doped water will be introduce in the prototype drainage layer in order to simulate the long term effects of the carbonates precipitation in the pore structure of the fill (chemical clogging). The carbonates precipitation is mainly dominated by the pH changes and leachate calcium content, since more than 80% of the precipitated carbonate is calcium carbonate. These facts allow the estimation of the calcium carbonate precipitation rate along the drainage layer life time and thus a more exact prediction of its long term performance.

5 PROTOTYPE STRUCTURE AND SIMULATION

The designed prototype will reproduce the specific determining factors acting in a leachate drainage layer which are mainly three: 1) geometry and structure of the drainage system, 2) vertical load due to the waste disposal, and 3) clogging generation due to mechanical, chemical and biological reasons related mainly to the leachate configuration.

In that sense, a multilayer configuration was designed (Figure 3), where is possible to reproduce the determining factors mentioned, in a controlled way. The structure can be separated in three main parts, deposed inside a 9m^3 methacrylate box.

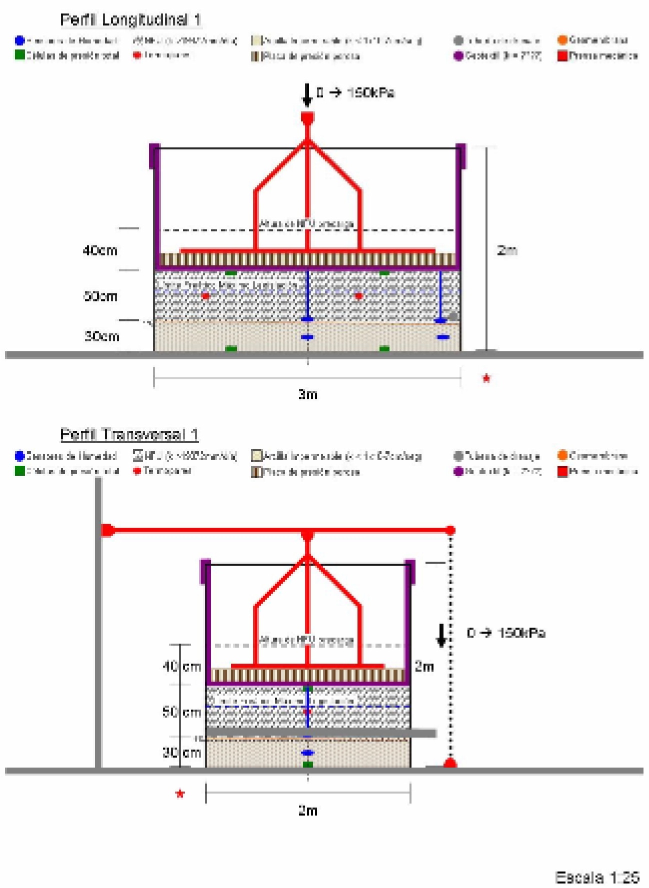

Figure 3.Structural scheme of the prototype designed.

The first part is the base or bottom liner, conformed of a clay non-permeable layer where instrumentation such loads cells and filtration detectors will be installed. This layer also will determine the drainage slopes (1% in each perpendicular direction).

The second part is the drainage layer filled with TDA shredded according to the ASTM standard and encapsulated within a non-permeable geomembrane (bottom) and a permeable non-woven geotextile (top). Inside the TDA layer a collection pipe will be embedded.

The last part is the vertical press system that will provide a controlled and variable vertical load using a system of levers and pulleys in order to increase gradually the load as it happens in real landfills through the production period.

Together with this configuration, a fluid recirculation system will be installed in order to circulate controlled doped water inside the drainage layer at a specific rate.

Several calibration tests will be performed by the prototype, before the execution of the main simulation, where during 20 days it will be reproduced the evolution of a real leachate drainage layer during a period of 80 years. In order to estimate the amount of leachate generated in a real landfill during that period, it was used the application H.E.L.P. (Hydrologic Evaluation of Landfill Performance - Environmental Laboratory USEPA), which provides feasible data, based on hydrological, meteorological and structural information. Also, it was used real records from Spanish landfills in order to estimate the increase of vertical load due to the storage of waste and the amount of calcium content and pH of the leachate along time.

6 DISCUSSION

The prototype suggested above, reproduce in 20 days the long term actions occurring in a landfill drainage layer filled with TDA, during a period of 80 years. Thus, time scale differences between the reality and simulation, introduce several expectations about the reliability of the device proposed. The first subject which is matter of discussion is the correct estimation of the drainage layer hydraulic conductivity that, in the case of the TDA and their high compressibility, it is a changing value due to the porosity changes in time produced by the waste vertical load, instead of a fix value as is use to be with granular materials, like gravel which porosity does not change a cause of the vertical load. For that reason, a prediction of the compressing behavior of the TDA layer and its implication on the variance of the hydraulic head of the drainage layer (Figure 4), based on the model presented above (McEnroe's model), will be compared with the prototype results, in order to prove its mechanical performance reliability. Similar comparisons (back analyses) will be performed for the others parameters to be measured in the prototype.

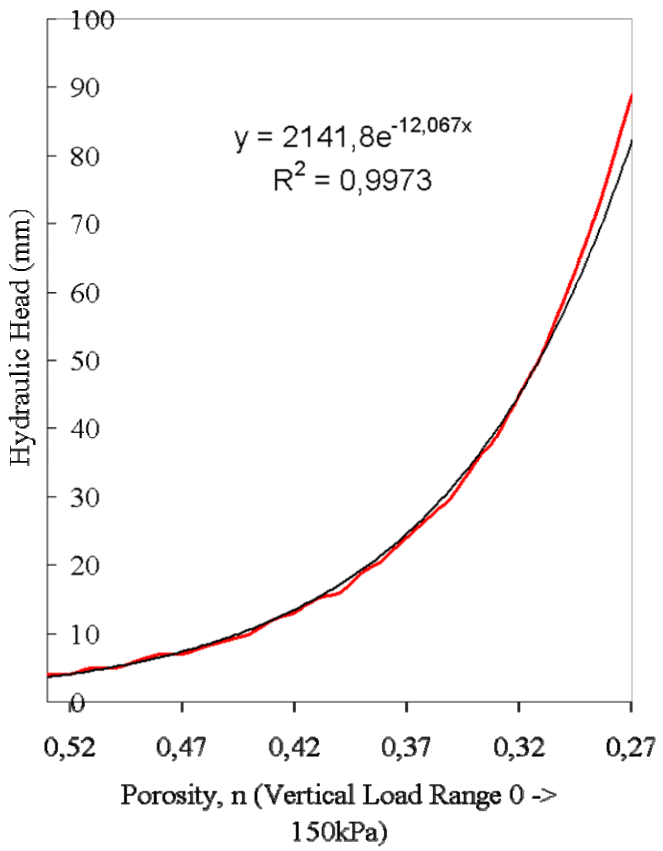

Figure 4.Hydraulic head predicted values for the TDA drainage layer embedded in the prototype.

7 CONCLUSIONS

Laboratory test together with previous works data, were used to develop a new designing method of landfills drainage layers, focused in two main aspects: 1) the specific determining factors introduced by the use of TDA as drainage fill material, and 2) the current Spanish (European) regulations.

In that sense, a combination of the newest calculation methods, software simulations and traditional geotechnical models of structural behavior were used in order to develop a big scale prototype that will reproduce the actions happening in a real landfill drainage layer proving the applicability of TDA in drainage systems and also the designing method here proposed.

However, further investigation have to be done regarding to TDA interaction with the environment, and also the pilot application of these technology in real landfills.

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