

# Performance and Time-Dependent Compression Behavior of Highway Fill Material Constructed Using Tire Derived Aggregate

Daniel Meles, Alireza Bayat & Somayeh Nassiri

*Department of Civil and Environmental Engineering, University of Alberta, Alberta, Canada*

Roger Skirrow

*Alberta Transportation, Alberta, Canada*

## ABSTRACT

Tire Derived Aggregate (TDA) is made by shredding scrap tires into 50 to 300 mm pieces, and has been successfully used as a fill material in various highway construction projects in the USA and other countries. To evaluate the performance of TDA in cold climate, a large-scale field experiment was performed in Edmonton, Alberta. The test embankment is 80 m long and contains four different test sections, each 20 m long. The embankment is also instrumented with temperature probes, settlement plates, and earth pressure cells. Falling Weight Deflectometer (FWD) tests were also conducted on the embankment after the placement of the 1 m soil cover, base course and asphalt. This paper presents the findings from FWD and the field instrumentation data that was collected during and post construction of the test embankment.

## RÉSUMÉ

Agrégat dérivés de pneus (TDA) est faite par déchiquetage en pneus usés de 50 à 300 mm pièces, et a été utilisé avec succès comme un matériau de remplissage dans divers projets de construction routière aux Etats-Unis et d'autres pays. Pour évaluer la performance de TDA dans un climat froid, une expérience de terrain à grande échelle a été réalisée à Edmonton, en Alberta. Le remblai d'essai est de 80 m de long et se compose de quatre sections d'essai différentes, chacune 20 m de long. Le talus est aussi instrumenté avec des sondes de température, des plaques de règlement et les cellules de pression des terres. La chute de poids déflectomètre (FWD) essais ont également été menés sur le quai après le placement du cours 1-m cache de la base du sol, et de l'asphalte. Cet article présente les résultats d'AV et les données d'instrumentation sur le terrain qui ont été recueillies pendant et après la construction de la digue de test.

## 1. INTRODUCTION

Tire Derived Aggregate (TDA) is defined as “pieces of scrap tires that have a basic geometrical shape and are generally between 12 and 305 mm in size and are intended for use in civil engineering applications” (ASTM D 6270-08). TDA is lightweight, free-draining, and has high thermal resistivity. It is used as fill for embankments, retaining walls and bridge abutments, and as an insulation layer to limit frost penetration. It is also used for French drains and as a drainage layer for roads (Humphrey 2008) and as leachate collection media. The use of TDA for civil engineering applications has economic and environmental benefits such as eliminating the need to store the discarded tires in landfill sites.

TDA can be produced from different discarded tire sources. The major source is Passenger and Light Truck Tire (PLTT). PLTT includes discarded tire that are designed for use on passenger, light and multipurpose passenger vehicle with rim diameter up to 19.5” (ARMA 2013). In some regions with heavy industrial and mining activities, such as the Province of Alberta, Canada, discarded tires from Off-The-Road tires (OTR) has also become a significant source of TDA. OTR include discarded tires designed for use on vehicles or equipment, including construction, mining, earthmover, and etc with rim diameter up to 39” (ARMA 2013).

In Alberta, TDA is used for landfill drainage application, however, the application of TDA as highway embankment fill is new. Specific traffic loading and

environmental conditions in Alberta require a study in the application of TDA for Alberta highway projects to ensure that it provides safety to road users as well as longer service life. In addition, the capability of tire recycling industries to process all types of waste tire into TDA and the growing stockpiles of discarded OTR encouraged Alberta Recycling and Alberta Transportation to investigate TDA as embankment fill material for highway projects.

To evaluate the performance of TDA in cold climate, a large-scale field experiment was performed in Edmonton, Alberta. The test embankment contains four different sections, made of two TDA fills from two different tire sources (PLTT and OTR), TDA from PLTT mixed with soil and a control section. This paper presents the field measurements that were collected during and after the construction of the test embankment.

## 2. PROJECT OVERVIEW AND CONSTRUCTION

The test embankment is 80 m long, and contains four different test sections, each 20 m long. The four test sections are made of 1) TDA from PLTT, 2) TDA from OTR, 3) TDA from PLTT mixed with soil at a 50/50 ratio by volume and 4) a control section made from native soil. PLTT was used as a base to compare the results of this study with similar projects reported in the literature. OTR, which is a significant waste in the province of Alberta,

Canada was used to evaluate the potential of this material for embankment applications for the first time. Mixing TDA with soil has advantages in reducing the potential for internal heating and decreasing the compressibility of TDA alone. The third section was made from PLTT mixed with fine grained soil. The last section is made from conventional fill (native soil) and is used as the control section. The test section has a 13 m wide transition zone tapering from full PLTT thickness at station 130 + 080 to zero thickness at 130 + 067, to provide a smooth transition between the test section and the conventional fill.

The embankment is instrumented with 30 temperature probes (Model 109AM-L), 25 Vibrating Wire Liquid Settlement Systems (model SSVW105), and six Vibrating Wire Total Earth Pressure Cell (model LPTPCP-V). All the sensors are connected to a data logger that collects and records the data at 15-minute intervals. TDA was placed in two layers, each 3-m-thick, and with 0.5-m-thick soil cap to separate the two layers, and 1-m thick soil cover, 450-mm base course and 160-mm of asphalt on the top. Figure 1 presents typical section of the test embankment and the instruments location.

The TDA and TDA-soil mix was placed with conventional construction techniques. First geotextile was placed on the prepare base. Then TDA and TDA-soil mix was spread in 300- or 500-mm lifts using a caterpillar dozer D7R XR series II. The 500-mm loose lift was used whenever the TDA or TDA-soil mixture was placed on top of the geotechnical instrumentation to avoid damage to the sensors by the construction equipment. Each lift was then compacted with six passes of a smooth drum vibratory caterpillar compactor CS 563D 109 kN.

During construction of the test section Falling Weight Deflectometer (FWD) tests were conducted after the placement of: the soil cover; the base course, and; the asphalt pavement. The tests were done on both outer wheel path and center line of the road at 5-m spacing; this resulted in 6 test points per section. For the subgrade FWD tests, four consecutive drop heights were done with target load of 5.8-, 8-, 10- and 12.3-kN; for the base course three consecutive drop heights with target load 23-, 31-, 40-kN, and for the asphalt pavement three consecutive drop heights with target load 26.7-, 40- and 53.3-kN were employed.

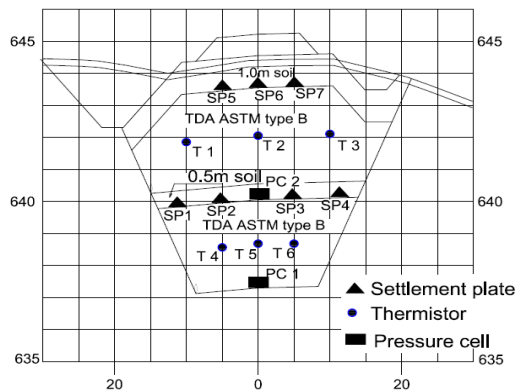


Figure 1 Typical cross section and instrumentation for the test embankment (all units in meters)

### 3. MATERIALS

#### 3.1. TDA

The TDA used in the construction of PLTT and OTR section was Class II fill (coarse TDA with maximum size of 300 mm for fill from 1 to 3 m) according to ASTM D 6270-08. Visual observation of samples taken during TDA production showed that PLTT contained TDA particles that were mostly thin and plate-like in shape, and OTR contained TDA particles that were thick and mostly irregular in shape. Figure 2 presents pictures of PLTT and OTR used in the project. Both PLTT and OTR satisfies the requirement of Type B TDA (ASTM D 6270-08): with 100 percent by weight passed 300-mm diameter sieve opening and maximum dimension of TDA measured in any direction was less than 400 mm, more than 75 percent by weight passed the 200 mm square mesh sieve, less than 50 percent by weight passed the 75 mm square mesh sieve, a maximum of 25 percent passed (by weight) the 38-mm square mesh sieve, and a maximum of 1 percent (by weight) passed the 4.75-mm sieve. Less than 1% of the TDA contained metal fragments that were not encased in rubber. Of the TDA particles with protruding steel wire of length 25- and 50-mm were less than 75% and 10% respectively, and overall the production was free from deleterious materials, such as grease, oil, diesel fuel, etc.



(a) PLTT



(b) OTR

Figure 2 Pictures of (a) PLTT and (b) OTR used in the project

### 3.2. Soil

The soil used for mixing TDA in the TDA-soil mix section as well as the soil used as intermediate and top soil cap was obtained from the site during the excavation for the test embankment. The soil is classified as Clayey sand (SC) according to the Unified Soil Classification System (USCS). It has more than 30 percent of the particles passing sieve No. 200. The maximum density and optimum moisture content were  $18 \text{ kN/m}^3$  and 16.5 percent, respectively, following the procedure available in ASTM D 98-07.

### 3.3. TDA and Soil Mix

The TDA (PLTT) and soil were mixed at a 50/50 ratio by volume (22/78 by weight) to be used in the TDA-soil mixture section. This ratio was selected based on past experience with the TDA-soil mixture test for embankment (Yoon et al. 2006). The PLTT was selected over OTR for the mixture due to its ample availability. The soil used for the mixture was native soil as described previously in the "Soil" section. It has moisture content close to optimum during mixing and placement of the mix. Mixing was performed using a caterpillar 345CL excavator with tooth-set edge bucket.

## 4. RESULT AND DISCUSSION

The test section utilized 4,054 tons of PLTT and 2,584 tons of OTR based on truck counts during the construction. The weight of TDA was estimated based on the weight of three randomly selected trucks loaded with each material type measured using a scale. Each tons of TDA is derived from approximately 100 discarded PLTT and 20 discarded OTR tires. It was estimated that a total of 4,054 tons of PLTT and 2,548 tons of OTR were used. Each ton of TDA is derived from approximately 100 discarded PLTT and 20 discarded OTR tires. Thus, the

project utilized an estimated 405,000 PLTT tires and 51,000 OTR tires, which is approximately 10 percent of the total tire generated in Alberta per year. The compacted unit weights for PLTT and OTR were computed using the geometry of the bottom TDA layer and weight of TDA at the end of the placement of the bottom TDA layer. The unit weights as compacted and compressed under its own weight were  $7.6\text{-}$  and  $8.1\text{-kN/m}^3$  for PLTT and OTR, respectively.

### 4.1. Result from Earth Pressure Cell

The stress measured from PC 2, located on the top of the bottom TDA layer for PLTT, OTR and TDA mixed with soil, is presented in Figure 3 as a function of time. The data in Figure 3 are total stress during the placement of the intermediate soil, top TDA layer, base course, asphalt and for 3 months period after the placement of the asphalt layer. The placement of the intermediate soil cover started on June 5, 2012, and the construction was completed on August 1, 2012. According to Figure 3, at the completion of placement of the top TDA and TDA-soil mixture layers, the additional stresses due to the weight of these layers were 31-, 32- and 55- kPa for the PLTT, OTR and TDA-soil mixture sections, respectively. The stress reading from the pressure cell for PLTT section is higher than that reported for other similar projects and unit weight back calculated from truck counts (Humphrey et al. 2000; Dickson et al. 2001). Even with the higher reading, the earth pressure cell indicated that both PLTT and OTR are light weight with total stress from the weight of PLTT and OTR approximately half the weight of normal soil fills. However, the additions of soil to TDA reduce its light weight property. Figure 3 also shows the stresses reading from all the three sections were constant during the post construction monitoring period.

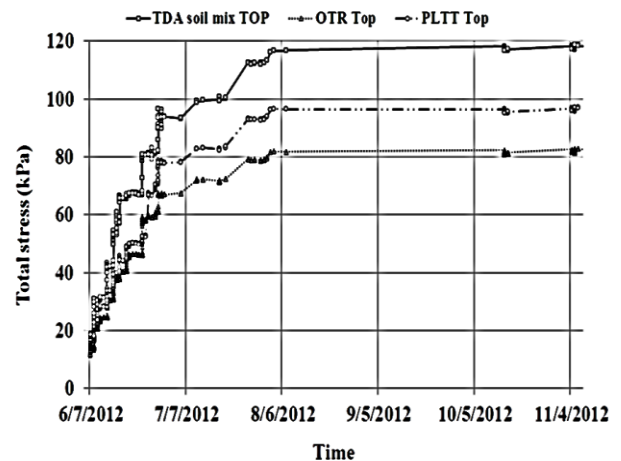


Figure 3 Total stress with time from earth pressure cell PC 2



#### 4.2. Settlement of the Test Embankment

Settlement measurements were taken for the top and bottom TDA layers in the three test sections and at a depth of 1.9 m for the control section. These measurements were taken both during the construction, and for about seven months after the placement of the asphalt layer. Typical settlement data by SP 6 for top TDA layer and SP 2 for bottom TDA layer in PLTT and OTR sections with time are presented in Figure 4. At the end of asphalt placement bottom TDA layer in PLTT and OTR sections settles by 50.4- and 38-cm respectively. Similarly the top TDA layers in PLTT and OTR settles by 51- and 38-cm respectively. Figure 4 also shows that at all stage of construction the settlements measured by settlement plate in PLTT sections were higher than those in OTR which shows PLTT is more compressible than OTR. Settlement plates in the TDA-soil mixture section and the control section did not show significant settlements compared to the OTR and PLTT sections. The maximum settlement for the TDA-soil mixture section was measured at 4- and 3.5-cm for the top and bottom layers, respectively during the construction period, and negligible settlement for the post construction period.

Post construction settlements data in Figure 4 indicate that top and bottom layer of TDA in OTR and PLTT sections undergo additional 7.3-, 3.4-, 3.6 – and 1.7-cm respectively. The additional strain taking initial compacted height of TDA (3 m) during seven months post construction monitoring period indicated that top TDA layer in OTR and PLTT sections had additional strain of 2.4 and 1.2% respectively. Unlike the settlement during construction where the PLTT settles more than OTR, the post construction settlement data indicated the opposite. The additional post construction settlement is more in OTR than PLTT section.

The stress and strain is computed using the field data at various stage of construction. Figure 5 presents the stress and strain computed using the data from total earth pressure cell and settlement plat for both OTR and PLTT sections at various stage of construction. Strain is computed by taking the ratio of settlement reading from settlement plate and compacted height of TDA (3 m for both PLTT and OTR). Settlement is computed using the average reading of settlement plate SP 5, SP 6 and SP 7 for the upper layer and SP 2 and SP 3 for the lower layer. The stress is computed using the total earth pressure cell PC 2. For the bottom TDA layer stress and strain are computed at the end of placement of 0.5 m intermediate soil cover, upper TDA, 1 m soil cover, base course and asphalt. Similarly for the top TDA layer after placement of 1 m soil cover, base course and asphalt. At all stage of construction the stresses and strains computed for PLTT were higher than for OTR section. A possible explanation for PLTT section higher stress and strain in comparison to the OTR section is that OTR was derived from very large and thick tires, resulting in TDA particles with granular shapes compared to PLTT with thin and plate-like particle shapes, which were easier to compact. This compression behavior was observed visually during the construction as well. OTR was observed to be stiffer than PLTT when

construction equipment moved around after compaction in preparation for the next lift. Fig. 7 also presents the comparison of stress strain measured in this study with previous case histories reported in the literature. The data measured for lower TDA in PLTT section agree with measurement reported by Upton and Machan (1993).

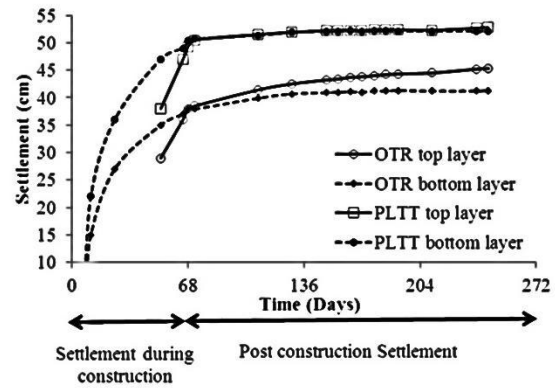


Figure 4 Settlement measured from SP 5 for PLTT and OTR during and after construction of the test embankment

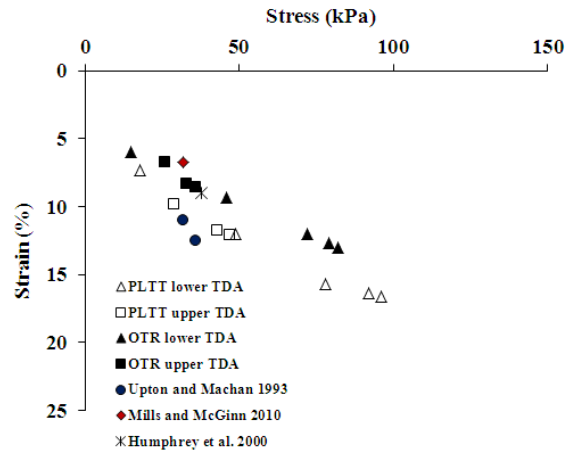


Figure 5 Stress and strain computed based on the field data in this study, and reported case histories in the literature

#### 4.3. Temperature Data

Typical temperature data are plotted in Figure 6. The temperature values presented in Figure 6 for the bottom layers in the three sections are the average of T4 to T6 (in Figure 1), respectively. Temperature sensors on the bottom layer of the three sections have ranged 14- to 18-°C, 13- to 17-°C, and 10- to 15-°C for PLTT, OTR and TDA and soil mixed sections respectively during construction and monitoring period after fill placement. The temperature measurements in both layers for the

three sections indicate no potential for internal heating during the monitoring period.

Relatively higher temperatures were measured for all section during construction with temperature showing decreasing trend after fill placement was completed. During the winter, all instrumented stations showed the warmest in the bottom TDA layer and the coolest temperature on in the upper portion which is opposite from what observed during construction on summer time. Temperatures less than 5°C were measured by the sensors in the top layer during winter period. This possible be due to the upper layer being close to the cool winter air during winter time, and TDA particle being exposed to a relatively longer time to the warm summer temperature before being placed and covered by the soil during summer time.

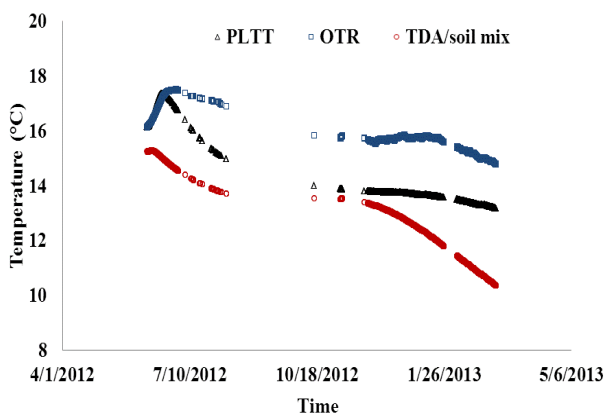


Figure 6 Temperature variations in the three sections during and after construction

#### 4.4. FWD Test Results

FWD tests were performed at various stages of construction to assess how the TDA or TDA/soil layer affected the stiffness of subgrade, base and asphalt layers in comparison with the control section. The tests were also conducted to see if the FWD could predict the longer term performance of the road. The test results for FWD load-center deflection data at various stage of construction is presented in Figure 8. In order to view the data on the same vertical scale in Figure 8, it was necessary to scale, or "normalize", the plotted FWD center deflections as per ASTM D5858-96. The following target or reference loads are used to normalize the deflection at various stages of construction: subgrade layer test (12 kN), base layer test (40 kN), and asphalt layer test (53 kN).

At subgrade level there is variation in FWD center deflection among the sections with the variation become negligible on the subsequent base and asphalt layer. Results from the subgrade FWD test showed that PLTT exhibits the maximum deflections. The deflection is the minimum for TDA and soil mixed section, which was the confirmed to be the least compressible among the three test sections. Although the results on base and asphalt

layer did not show significant difference in center deflection, PLTT, OTR and TDA/soil appear to represent a softer subgrade than the control section which is constructed from normal fill. As the FWD test result give more or less similar center deflection for the three sections in comparison with the control section, design modification for the thickness of the base course was not necessary during construction.

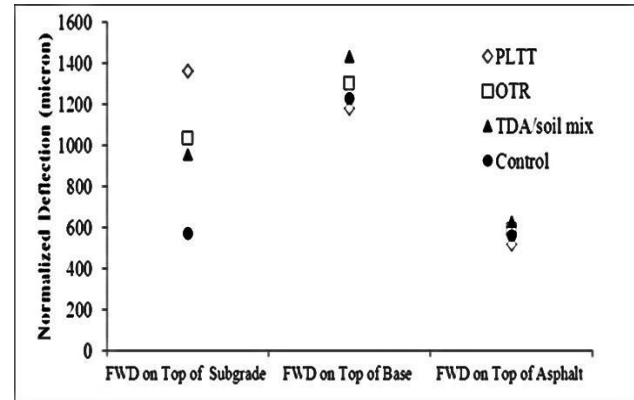


Figure 8 Normalized deflections from FWD on top of subgrade, base and asphalt layer

#### 5. CONCLUSIONS

A test embankment that contained four sections was constructed on access road in Edmonton, Canada. The four sections composed of PLTT, OTR, PLTT-soil mixture and a normal soil as a fill material. The embankment was instrumented with various geotechnical sensors to see the construction and performance of TDA fill. Based on the investigation and analysis of the monitoring data, the following observations and conclusions can be drawn:

1. Immediate settlement measurements at the end of construction indicated that PLTT and TDA-soil mixture sections show the maximum and minimum settlements, respectively.
2. The data from the settlement plates indicated PLTT was more compressible than OTR
3. Post construction settlement showed that OTR undergo more additional settlement than PLTT.
4. The earth pressure cell indicated that both PLTT and OTR are light weight with compacted unit weight approximately half the unit weight of normal soil fills. However, the additions of soil to TDA reduce its light weight property.
5. Monitoring the embankment with the temperature sensor indicate no evidence of internal heat generation during construction and for six months after placement of the asphalt.
6. FWD test results on top of subgrade showed that PLTT, OTR and TDA mixed with soil section represent relatively weaker subgrade compared to the control section.

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