EVALUATION OF TIRE MATERIAL AS PAVEMENT EMBANKMENT

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ABSTRACT
Recently, the tendency to use recycled and waste materials in the construction industry has significantly increased. The use of tire derived aggregates (TDA) could be an economical, sustainable, and environmentally friendly solution instead of using raw granular aggregates. This paper investigates and compares the seasonal performance of a road pavement comprised of tire embankment material to a conventional pavement on a test road in Edmonton, Alberta, Canada.
The test road included three different sections constructed using TDA materials. The first section was comprised of passenger and light-truck tires (PLTT); the second section included off-the-road (OTR) tire particles; and the third section was made of embankment layers with a mix of PLTT and local subgrade soil. A conventional pavement section was constructed adjacent to these sections as a control section. To investigate the performance of the pavement at different sections, falling weight deflectometer (FWD) tests were conducted on both tire sections and the control section in different seasons. The back-calculation results of FWD tests revealed that the subgrade of the TDA sections showed higher deflection and a lower resilient modulus compared to the control section; however, maximum pavement deformation was higher in the control section.

RÉSUMÉ
Actuellement, la tendance à utiliser des matériaux recyclés et des déchets dans l'industrie a considérablement augmenté. Cela pourrait être une solution économique, durable et écologique au lieu d'utiliser des granulats granulaires bruts. Cet article étudie et compare les performances saisonnières d'un revêtement routier composé de matériaux de remblai de pneus à un revêtement conventionnel sur une route d'essai à Edmonton, Alberta, Canada.
La route d'essai comprenait trois sections différentes construites en utilisant des matériaux TDA. La première section comprenait des “passenger and light-truck tires (PLTT)”; la deuxième section comprenait des “off-the-road (OTR) tire particles”; et la troisième section a été faite de couches de remblai avec un mélange de PLTT et de sol de sous-sol local. Une section de chaussée conventionnelle a été construite à côté de ces sections en tant que section de contrôle. Pour étudier la performance de la chaussée à différentes sections, des “falling weight deflectometer (FWD) essais ont été effectués sur les deux sections de pneus et la section de contrôle à différentes saisons. Les résultats du rétrocalcul des essais FWD ont révélé que la sous-couche des sections TDA présentait une déflexion plus élevée et un module élastique inférieur par rapport à la section témoin; cependant, la déformation maximale de la chaussée était plus élevée dans la section de contrôle.

1 INTRODUCTION

Scrap tires are shredded to produce tire-derived aggregate (TDA). TDA is a lightweight material that has a lower thermal conductivity than soil, a high hydraulic conductivity, good insulating properties, and the capability to promote drainage as a result of the material containing large air voids (Humphrey, 2008). These above qualities make it an effective embankment fill in many highway construction projects (Hoppe and Mullen, 2004; Badlia, 2015; Oman, 2013). Every year, approximately 300 million scrap tires are generated in the U.S. (Rubber Manufacturer Association, 2016); more than 33 million are generated in Canada, of which 5 million are produced by Alberta alone (Alberta Recycling Management, 2015). Scrap tires create some negative environmental impacts, the biggest issue being tire stockpiles, the unsightly view the piles create, the fire hazards they become if disposed of carelessly, and, consequently, rising toxic chemicals from the smoke if they catch fire.

TDA may be produced from passenger and light-truck tires (PLTT), which are mostly thin and plate-like in shape, or heavy industry off-the-road (OTR) tire particles, which are thick and mostly irregular in shape (Figure 1). In highway embankment applications, TDA material can be completely or partially substituted with soil. TDA materials are highly compressible, which can result in embankment settlement. One of the main challenges of using tire material as road embankment is its high settlement potential during construction, about twice as much as a conventional soil embankment (Hoppe and Mullen, 2004; Meles et al, 2014). Investigations show that the long-term settlement could be minimized using a surcharge after a period of at least six months post project completion (Hoppe and Mullen, 2004; Meles et al., 2014).

Figure 1. Tire-derived aggregate material

TDA material has been used in various road and highway construction projects (Siddique and Naik, 2004; Tandon et al., 2007); however, there are few projects that compare the performance of roads constructed using TDA with the performance of a road constructed using conventional soil embankment. This study investigates the seasonal variations in the resilient modulus of subgrades of three pavement sections constructed using different types of TDA embankments compared to behaviour of a conventional pavement. For this purpose, monthly FWD tests were conducted for a full year on different sections of the Integrated Road Research Facility (IRRF) test road. It should be mentioned that the test was not performed on December, January and February because the pavement was frozen and extremely stiff. After back-calculation of FWD data in different months, the resilient modulus of the subgrade layer was calculated and compared with the results from the conventional section.

1.1 IRRF Test Road

Construction of the IRRF's test road facility, located on the eastern edge of Edmonton, started in May 2012. The pavement structure for the test road comprises 250 mm of Hot Mix Asphalt (HMA), which was placed in two stages of a 160 mm binder layer and a 90-mm wearing course. The HMA layers were placed on 450 mm of granular base course with a maximum size of 19 mm aggregates, on 1 m of compacted clayey-sand subgrade soil. The first 160 mm asphalt layers of the test road were laid in August 2012 and the top 160 mm layers were constructed in October 2013. It has two lanes, is approximately 500 m long, and since October 2015 has been carrying 2000 trucks each day.

As is shown in Figure 2, the test road includes three main test sections, including: 60 m of TDA fill embankment, two different 20 m pavement monitoring sections, and a 60-m insulated section. The Edmonton Waste Management Centre's weather station, located approximately 1 km from the test road, is used to monitor climatic indices.

The tire material sections include three 20 m sections made of PLTT, OTR, TDA, and native soil mixture. To minimize the possibility of firing due to internal heating, the embankment was divided into two layers with an uncompressed thickness of 3 m. Each layer was wrapped in a nonwoven geotextile layer in order to prevent surrounding soil penetration to the tire layers. To separate the two tire layers from each other, 0.5 m of soil was compacted on top of the lower layer (between the two layers). The upper tire layer was covered with 1 m of low-permeability soil. The schematic cross section of the tire material sections is shown in Figure 3.

The grain size distribution of TDA materials was determined according to type B TDA particle size requirements according to American Standard for Testing and Materials (ASTM D6270, 2008). For constructing the third tire material section, 50% of PLTT and 50% of native soil (by volume) were mixed. The reason behind using PLTT over OTR was its availability at the time.

The test embankment was instrumented with two types of geotechnical sensors to monitor and evaluate the construction process, as well as the immediate and long-term settlement of the embankment (Meles et al., 2014, Hashemian and Bayat, 2017).

2 FALLING WEIGHT DEFLECTOMETER TESTING

Falling Weight Deflectometer (FWD) simulates the dynamic load of a moving vehicle. This is a non-destructive test and has become a well-known method to calculate the resilient modulus of pavement layers. The FWD equipment used for this study included nine geophones, the first one under the centre of the loading plate, followed by a distance of 200, 300, 450, 600, 900, 1200, 1500, and 1800 mm from the center of the first geophone. Figure 4 shows the geophone's configuration. As Table 1 shows, several FWD tests were conducted on all sections of the IRRF's test road. At each station, three stress levels of 26.7, 40.0, and 53.3 kN were applied and the results of deflections under stress levels of 40 kN were normalized to be used for investigation purposes.

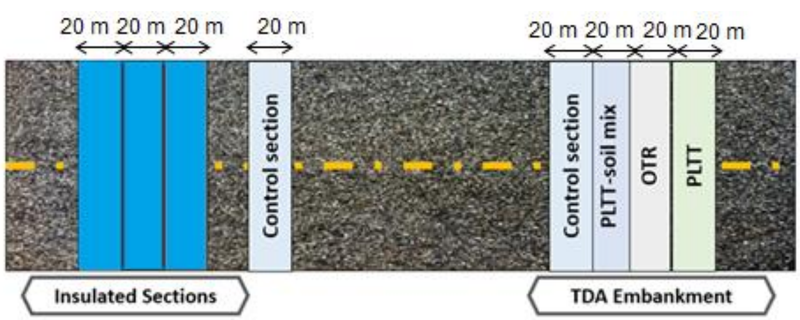

Figure 2. Schematic plan of the IRRF test road

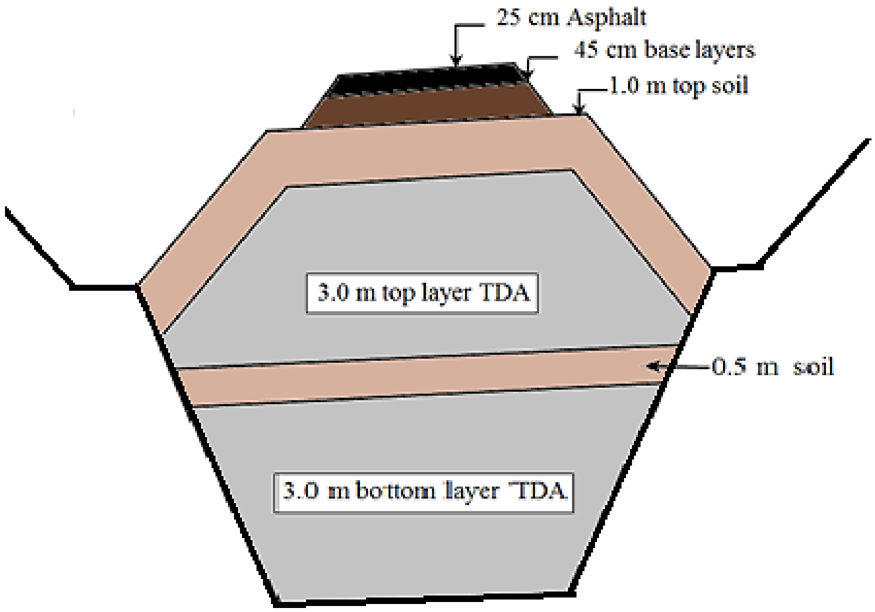

Figure 3. Typical pavement section including tire embankment

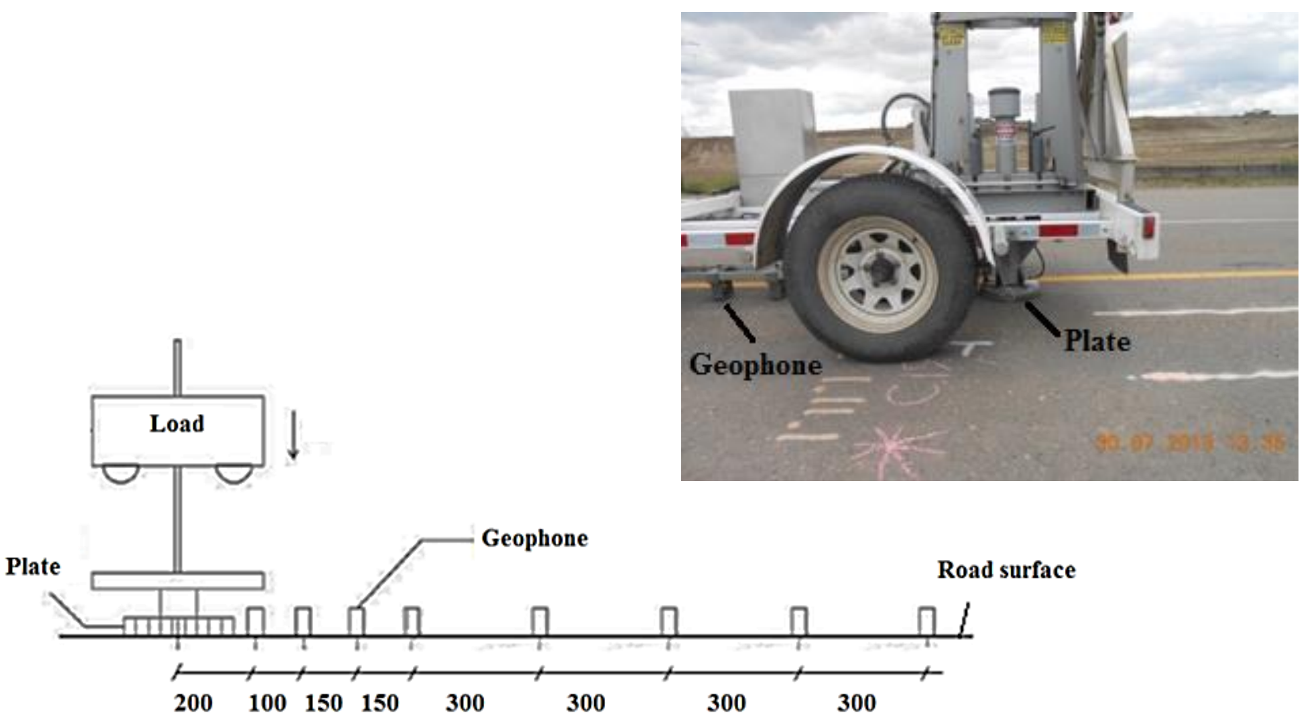

Figure 4. FWD device and geophones configuration

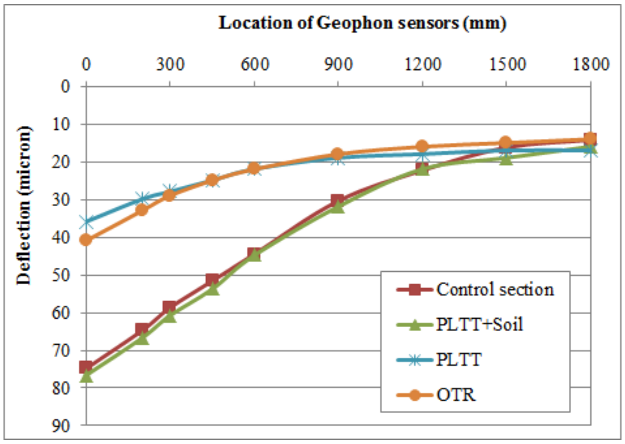

Figure 5. FWD deflection bowls, 14.March.15, temp 2°C

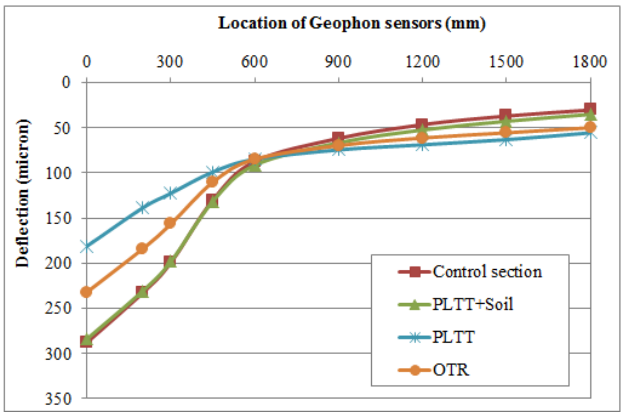

Figure 6. FWD deflection bowls, 25.May.15, temp 35° C

Table 2 shows the maximum deflection under the loading plate (D0) for all FWD tests at different months.

As can be observed in Table 2, the lower the asphalt temperature, the lower the D0 in all sections. These numbers could be the result of a lower temperature in the asphalt layer and consequently, its higher modulus (Shafiee et al., 2015). In all months except November, D0 is lower in the PLTT and OTR sections compared with the PLTT+soil and control sections. The reason for having lower deflection in the control section and the PLTT+soil section could be related to the fact that the soil was frozen at that time (Tavafzadeh et al, 2016) and the subgrade of those sections was stiffer than that of the tire sections.

2.1 FWD back-calculation results

To calculate the subgrade resilient modulus (M_r) based on FWD data, this study used the AASHTO method (AASHTO, 1993) (Equation 1):

$$M_r = \frac{0.24 \times P}{D_r \times r} \quad [1]$$

Table 2. FWD first and seventh sensor deflection (µm)

Date	Section	D0	D7
20-Jul-14	PLTT	147	55
	OTR	190	58
	PLTT+S	218	56
	CS	216	51
5-Sep-14	PLTT	133	63
	OTR	172	63
	PLTT+S	204	60
	CS	198	54
17-Oct-14	PLTT	88	49
	OTR	109	49
	PLTT+S	136	37
	CS	140	30
18-Nov-14	PLTT	38	30
	OTR	37	27
	PLTT+S	32	20
	CS	33	20
12-Mar-15	PLTT	36	18
	OTR	41	16
	PLTT+S	79	22
	CS	75	22
08-Apr-15	PLTT	81	49
	OTR	109	49
	PLTT+S	145	61
	CS	147	58
21-Apr-15	PLTT	96	55
	OTR	133	53
	PLTT+S	165	50
	CS	150	44
5-May-15	PLTT	107	59
	OTR	143	60
	PLTT+S	178	61
	CS	178	56
25-May-15	PLTT	181	69
	OTR	232	61
	PLTT+S	284	52
	CS	288	47
5-Jun-15	PLTT	189	71
	OTR	237	66
	PLTT+S	294	65
	CS	293	57
9-Jul-15	PLTT	376	83
	OTR	422	76
	PLTT+S	460	69
	CS	462	60

In this equation, P is the target FWD load (kg), $\mathrm{M_r}$ is the resilient modulus of the subgrade (kg/cm^2), D_r is the deflection at distance r from the loading plate (cm), and r is the distance of the selected geophone from the loading plate (cm). To back-calculate the subgrade modulus using this method, a sensor should be selected far enough from the center of the loading plate to ensure that the other pavement layers do not affect the deflection. For this reason, the selected location should be compared to $0.7 \times \mathrm{a_e}$, which is calculated from Equation 2:

$$a_e = \sqrt{\left[a^2 + \left(D\sqrt[3]{\frac{E_p}{M_r}}\right)^2\right]} \qquad [2]$$

In Equation 2, $\mathrm{a_e}$ is the radius of the stress bulb at the subgrade-pavement interface (cm), a is the load plate radius (cm), D is the total thickness of the pavement layers above the subgrade (cm), and E_p is the effective modulus of the pavement above the subgrade (kg/cm^2).

Considering the existing pavement thickness of 70 cm, the sensor that most accurately reflected subgrade deflection was found to be the sensor at a distance of 1200 mm from the first geophone under the loading plate. Using the deflection data from the seventh sensor (D7 from Table 2), the $\mathrm{M_r}$ values were calculated as shown in Figure 7.

As Figure 7 shows, the resilient modulus ($\mathrm{M_r}$) is nearly constant for the subgrades of the control and PLLT+soil sections for all but the cold months when the surface temperature is low. The highest value for the subgrade resilient modulus is for November, with a surface temperature of -1 degrees Celsius: in this case, the asphalt modulus is highest, the stress that reaches to the subgrade is minimized, and the subgrade soil is frozen. In March, the subgrade is still partially frozen and has a high resilient modulus, but in April there is a sudden drop, as a result of the thawing of the frozen subgrade, negatively affecting the resilient modulus.

The PLTT and OTR sections show the highest subgrade resilient modulus in March, when both the pavement temperature and tire embankment are low, affecting the stiffness of the tire material. The lowest subgrade resilient modulus in the tire material section is during the warmest month (July 2015), when the tire material temperature is high and the stiffness is low.

Figure 8 compares the resilient modulus of the subgrade in all three tire material sections with the subgrade in the control section. As can be seen in Figure 8, in every month except for March 2015 and early April 2015, the resilient modulus of the tire material sections is lower than the control section. In mid-March and early April, when the subgrade of the control section is affected by thawing, the subgrades of the tire material sections are stronger. However, in colder months such as November, when the subgrade is frozen, the resilient modulus of the control section is actually higher than that of the tire material sections. In all seasons, the resilient modulus of the PLTT+soil section has the minimum difference with the control section. In warmer months, the resilient modulus values of all the sections are closer to each other. This observation shows that by increasing the temperature, the tire material sections behave similarly to a flexible material.

Comparison of Figures 7 and 8 to Table 2 shows that in most cases, tire material sections have a lower resilient modulus than the control section, but the maximum deflection of these sections is always lower as well. The only exception is in November 2015 when the pavement of all sections is frozen making the maximum deflection of the control section lower than the tire material sections.

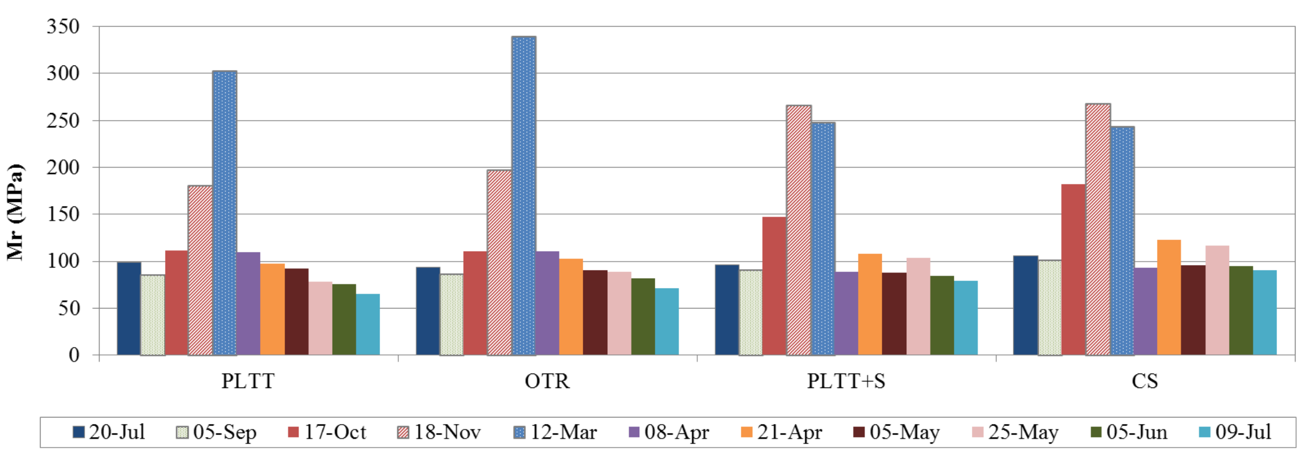

Figure 7. Resilient modulus of different sections

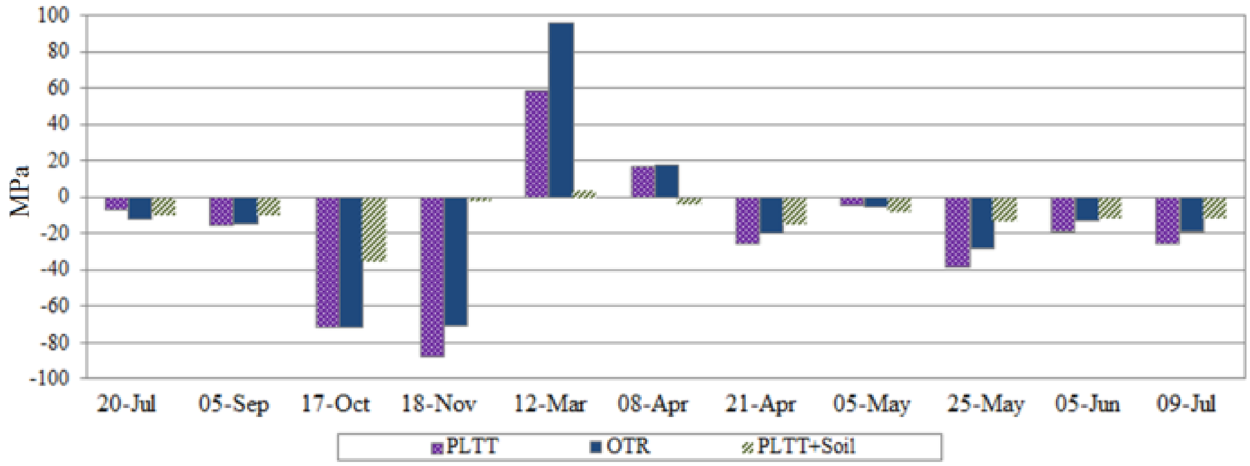

Figure 8. The difference in resilient modulus between the tire sections and the control section.

3 CONCLUDING REMARKS

This paper investigated pavement responses to loading during seasonal changes. The study was conducted by creating and measuring three different types of tire-filled embankment pavements and comparing the results to a conventional pavement section as a control. FWD test results from different seasons two years following completion of the construction of the IRRF test road were used to calculate the resilient modulus of the three different sections. The conclusions are summarized as follows:

- Under the FWD loading plate, the sections composed of tire embankments (PLTT or OTR) showed lower deflection compared with the PLTT+soil and control sections.
- The subgrade deformation under the FWD test was highest in the PLTT section, followed by the OTR section. Subgrade deformation in the PLTT+soil and control section was lower than the other two sections.
- The PLTT and OTR sections had a smaller area under the FWD test deflection bowls compared to the PLTT+soil and control sections, especially in cold seasons. Meaning that tire embankment pavements are less flexible than conventional pavements.
- The resilient modulus of the subgrade was lower in the PLTT and OTR sections compared to the PLTT+soil and control sections; however, the total deflection of the PLTT and OTR sections was lower. This observation can be related to how tire material behaves differently under loading compared to how soil behaves under loading.
- The PLTT+soil section performance under loading showed more similarities with the control section than it did with the PLTT and OTR sections.
- Embankments constructed with TDA resulted in comparable FWD tests to the control section constructed using compacted soil.

4 ACKNOWLEDGEMENTS

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