Field & Laboratory Characterization of Tire Derived Aggregate in Alberta

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Paper prepared for presentation at the Innovation in Geotechnique for Transportation Session
of the 2013 Conference of the Transportation Association of Canada
Winnipeg, Manitoba

ACKNOWLEDGEMENTS

The authors greatly appreciate Alberta Recycling for providing Tire Derived Aggregate and financial support for the project and laboratory testing, and Alberta Transportation for their financial contribution. We would also like to thank Mr. Greg Lewin from Edmonton Waste Management Centre and University of Alberta students for their help during the construction and instrumentation of the project.

ABSTRACT

Tire Derived Aggregate (TDA) is made by shredding scrap tires into 50 to 300 mm pieces. This material is lightweight and has higher permeability and thermal resistivity than soil. Because of these properties, TDA has been successfully used as a fill material in various highway construction projects in the United States and other countries. Moreover, recycling discarded tires has economic and environmental benefits, such as eliminating the need to store waste tires in landfills. In order to evaluate the performance of TDA as fill material in cold climates, a large-scale field and laboratory experiment was performed in Edmonton, Alberta. The field test embankment, which used nearly 7,000 tons of discarded tires, is an 80 m instrumented test road and contains four sections: 1) TDA from Passenger and Light Truck Tires (PLTT), 2) TDA from Off-The-Road truck tires (OTR), 3) TDA from PLTT mixed with soil and 4) native soil (control section). Large-scale, one-dimensional laboratory compression tests were also performed to characterize the compression behavior of different TDA material. The paper presents the test results and the findings of the field instrumentation.

Introduction

In civil engineering applications, recycled tires are used in a shred form referred to as tire shred or Tire Derived Aggregate (TDA). TDA are defined as “pieces of scrap tire that have a basic geometrical shape and are generally between 12 to 305 mm in size and intended for use in civil engineering application” (1). Several studies have been conducted to identify the feasibility of using shredded tires as a lightweight embankment fill or backfill material in highway projects (4, 7, 14, and 8). These studies suggested that TDA perform better or similar to conventional fill. Moreover, TDA has the added benefit of reducing tire waste and reducing demand for natural, non-renewable aggregate material such as gravel

TDA is produced from different tire sources. The primary sources of TDA are Passenger and Light Truck Tires (PLTT) because they are more widely available and easily manufactured into TDA (13). In some regions with heavy industrial and mining activities, such as the Province of Alberta, Canada, discarded Off-The-Road (OTR) tires have also become a significant source of TDA. 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. This paper presents the experimental results obtained from field study and large-scale laboratory tests conducted by the University of Alberta to determine the performance of TDA derived from OTR and PLTT.

Research Objective and Approaches

The two primary objectives of this study are: 1) to discuss the stress-strain behaviour obtained from field instrumentation of an experimental test embankment, and 2) to characterize the physical and mechanical properties of TDA from OTR and PLTT in the laboratory using large-scale, one- dimensional compression tests.

The stress-strain behaviour in the field was obtained using the data measured using field instrumentation. Settlement plates and total earth pressure cells that were used to monitor the construction of the test embankment were employed to characterize the stress-strain behaviour for OTR and PLTT in the field. Strain and stress data were computed during the placement of subgrade soil cover, base course and asphalt layer.

A laboratory experimental program was designed to study the one-dimensional compression behaviour of PLTT and OTR. Compression tests were conducted, using a large-scale compression cell at various initial unit weights. Unit weights of 4.9, 5.6 and 6.0 kN/m^3 were used for PLTT, and unit weights of 4.8, 5.8, 6.0 and 6.5 kN/m^3 were used for OTR.

Compression behavior from the field

Project Overview

The test embankment was constructed for an access road project that connects Anthony Henday Ring Road to the Edmonton Waste Management Centre (EWMC) in Edmonton, Alberta. The test embankment is 80 m and contains four 20 m test sections, which 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) native soil (control section). In the PLTT and OTR sections, TDA was placed in two layers, each 3 m thick and wrapped in geotextile with a 0.5 m thick soil cap to separate the two layers. A 1-m compacted soil cover, plus a 450-mm thick base course and a 160-mm asphalt concrete layer were placed on top the upper TDA layer.

The embankment was instrumented with geotechnical instrumentation to monitor construction and long-term performance. The instrumentation includes settlement plates and total earth pressure cells. A total of 14 Vibrating Wire Liquid Settlement Systems (model SSVW105), calibrated and supplied by RST Instruments, were used to monitor potential settlement in PLTT and OTR test sections. Of the 14 sensors, seven sensors were installed in each of the PLTT and OTR sections. A total of four Vibrating Wire Total Earth Pressure Cells (model LPTPCP-V), two at each section, calibrated and supplied by RST, were used to monitor the vertical stress during construction in PLTT and OTR sections. All the sensors are connected to a CR1000 data logger that continuously collects and records the data at 15 minute intervals. Figure 1 presents typical section and instruments location for settlement plate and earth pressure cell for PLTT and OTR.

MATERIALS

TDA

The TDA used in the construction of PLTT and OTR sections was Class II fill (coarse TDA with maximum size of 300 mm for 1 to 3 m fill) according to American Standard for Testing and Materials (ASTM) D 6270-08 (1). Figure 2 presents pictures of PLTT and OTR used in the project. Visual observation of samples taken during embankment construction showed that TDA particles derived from PLTT were mostly thin and plate-like in shape, and TDA particles derived from OTR were thick and mostly irregular in shape. Moreover, the samples were checked to make sure the gradation satisfies Type B TDA particle size requirements and other criteria advised by ASTM D 6270-08 (1). Both PLTT and OTR used in the project satisfied the requirement of Type B TDA: with 100 percent (by weight) passed 300-mm diameter sieve opening and maximum dimension of TDA measured in any direction was less than 300 mm, more than 75 percent (by weight) passed the 200 mm square mesh sieve, less than 50 percent (by weight) passed the 38-mm square mesh sieve, and less than 5 percent (by weight) passed the 4.75 mm sieve. Moreover metal fragments and protruding steel wire satisfied the ASTM D 6270-08 (1) requirements, and overall the production was free from deleterious materials, such as grease, oil, diesel fuel, etc.

Construction

Construction started by excavating an approximately 8 m deep and 60 m long pit with 17 and 40 m bottom and top widths respectively, to accommodate the test sections. A picture of the test site is presented in Figure 3. A caterpillar excavator 345CL, caterpillar dozer D7R XR Series II and a smooth drum vibratory caterpillar compactor CS-563D 109 KN were used to construct the test embankment. TDA in PLTT and OTR sections was placed in a combination of 500 and 300 mm loose lift, and compacted by six passes compactor. The 500 mm loose lift was used whenever the TDA was placed on top of the geotechnical instrumentation to avoid damage to the sensors by the construction equipment. There were no major problems observed during construction. However, there were minor issues manoeuvring the dozer to spread TDA to the appropriate lift and difficultly achieving a smooth surface after compacting each lift. It was also visible during construction that PLTT was more difficult to compact and relatively spongier compared to OTR. No instances of tire puncture were reported during the construction.

Results from Instrumentation

Short-Term Settlement of the Test Embankment

Settlement measurements were taken for the top and bottom TDA layers in OTR and PLTT sections at various stages of construction. The settlement of the bottom TDA layer measured by SP 1 to SP 4 for the PLTT and OTR sections are presented in Figures 4 (a) and (b), respectively. The settlement of the top TDA layers measured by SP 5 to 7 for the PLTT and OTR sections are presented in Figures 4(c) and (d), respectively. The settlement measurements are presented at five stages of construction for the bottom layers and three stages for the upper layers. Stage 1 of construction corresponds to the placement of the intermediate 0.5 m soil cap, Stage 2 to the placement of the top TDA layer, Stage 3 to the placement of the top 1 m soil cover, Stage 4 to placement of the base course, and Stage 5 after the placement of the asphalt.

According to Figures 4 (a), (b), (c) and (d) for both the PLTT and OTR sections, settlement increased as the stress level increased and the construction progressed. At all stages of construction the settlements measured in the PLTT section were higher than the measurements for the OTR section. The maximum settlement was observed in Stage 5 and is approximately 51 and 38 cm for the PLTT and OTR sections, respectively. It should be noted that the data for SP 1 in the OTR section in Figure 4 (b) was not recorded in Stage 2. A possible explanation for the higher settlements of the PLTT section 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 and attained higher compacted density during field compaction. Moreover Figures 4 (a), (b), (c) and (d) show that most of the settlement occurred at the end of placement of 1 m soil cover. For PLTT section more than 90% and 80% of the total settlement occurred at the end of placement of 1 m soil cover for bottom and top layers respectively. Similarly for OTR section around 92% and 75% of the total settlement occurred at the end of placement of 1 m soil cover for bottom and top TDA layers respectively. The authors' thinks that the decrease in settlement at later stages during placement of base course and asphalt compared to the others stages may be associated to the compression behaviour of TDA observed in the laboratory by Wartman et al. 2007 (15) that initial increment of stress result in significant compression after which the specimen become less compressible as the strain accumulate and the material strain hardens.

Stress-strain behaviour from field data

Figure 5 presents the stress and strain computed using field data for both OTR and PLTT sections after placement of the intermediate soil cover, upper TDA, top 1 m soil cover, base course and asphalt layers. Strain was computed by taking the ratio of the settlement reading from the settlement plate at the end of each stage of construction to the compacted height of TDA (3 m for both PLTT and OTR). Settlement was computed using the average reading of SP 5, SP 6 and SP 7 for the upper layer and SP 2 and SP 3 for the lower layer. Stress was computed using the total earth pressure cell (PC 2), located on the bottom TDA layer. According to Figure 5 for equal stresses, the strain computed for the OTR section was lower than the PLTT section.

Stress-strain behavior from laboratory experiment

Gradation, specific gravity and water absorption

The particle size distribution for the TDA material used in the study is presented in Figure 6. Visual observation of the TDA particles indicate that PLTT contained TDA particles mostly thin and plate like in shape. Compared to PLTT, OTR contained TDA particles that are thick, irregular in shape, with relatively more steel wire protruding from the cutting surface. Nonetheless, in both PLTT and OTR, the steel protruding from the surface is very short and in compliance with the ASTM D6270-08 (1) requirement. Specific gravity and water absorption tests were conducted in accordance with ASTM C 127 (2) except at the start of the water absorption tests, air-dried samples were used instead of oven-dried samples. Specific gravity and water absorption are 1.27 and 1.1 percent for OTR, and 1.31 and 1.9 percent for PLTT, respectively. The values obtained for specific gravity agree with results reported by Edil and Bosscher, 1994 (5).

Apparatus and test procedure

The experimental program was designed to study the one-dimensional compression behaviour of both TDA types at different initial unit weights. A picture of the compressibility testing apparatus is provided in Figure 7. The equipment contained a polyethylene cylindrical tube connected to a hydraulic system. The compression tube has an inside diameter of 57 cm, a height of 112 cm, and a thickness of 20 mm. The 20 mm polyethylene wall is thick enough to restrain the lateral deformations under axial loading. The inner diameter of the compression cell was approximately four times larger than the largest TDA piece. The equipment was able to apply pressures up to 200 kPa. Loads were applied incrementally on top of the samples using a steel plate with a thickness of 2 cm and a diameter of 56 cm. The lowest unit weights were obtained by loosely dumping the TDA in the compression cell and were only subjected to a vertical load of 50 to 60 KPa. The remaining tests were made by applying a vertical load up to 200 KPa.

Friction between the TDA particles and the inner surface of the cells was a concern in the use of such large-scale compression equipment. To minimize the side friction, three trial tests were performed on PLTT samples. In the first trial, compression tests were conducted such that the TDA particles were in direct contact with the sides of the cells. For the second trial, the interior surfaces of the cells were lubricated with grease. For the third trial, the interior surfaces were first lubricated using grease and later covered by a plastic sheet. In each case, a load cell was used to measure the pressure at the bottom of the cell to find the load reduction due to the friction. The first trial gave maximum frictional loss, with stress at the bottom measuring up to 60 percent less than stress at the top. The third trial measured a minimal amount of stress at the bottom, which was 25 to 30 percent lower than the stress at the top, and was adopted for the experiment. To further account for side friction, the average stress at the top and bottom of the sample were used at each stage of load increment to compute the strain. The stresses at the top of the sample were measured using a load gage attached to the compression apparatus, and the stresses at the bottom were measured using a load cell.

One dimensional compression test result

The stress-strain plot for both TDA types, with stress on logarithm scale and strain on normal scale, are presented in Figure 8(a) and (b). Both plots indicate a decreasing trend of compression with increasing initial unit weight of the sample, as was noted by Humphrey, 2008(8). Except for the cases where TDA samples were placed loosely in the compression apparatus, the results for both TDA types show the slopes of stress (on logarithm scale) versus strain are comparable for samples tested at different initial unit weight when the stress is greater than 30 kPa. For OTR, the logarithm fit for stress greater than 30 kPa gave a slope value of 11 for samples with unit weight 6.3- and 6.5-kN/m^3, and a slope of 12 for sample with initial unit weight 5.8 kN/m^3. Similarly for PLTT both samples with initial unit weight 5.6- and 6-kN/m^3 gave a slope value of 11 on linear logarithm fit. The samples placed loosely in the compression apparatus for both OTR and PLTT were highly compressible with up to 25% strain for a vertical stress of 40 kPa.

Comparison of stress strain obtained from field and large scale laboratory tests

A comparison on stress- strain, computed using field instrumentation and large-scale, one-dimensional constrained tests, is presented in Figure 9 (a) and (b) for OTR and PLTT respectively. For the laboratory test, only compression curves with initial unit weight greater than 6 kN/m^3 is considered for comparison as field compaction usually results in compacted density greater than this value. In the case of OTR shown in Figure 9(a), stress strain computed based on field measurement approaches the laboratory compression curve for samples with initial unit weight of 6.3 kN/m^3 for the first stage of construction for the lower TDA and the last three stages of construction for upper TDA layer. In the case of PLTT shown in Figure 9(b), except for the first stage of loading for the upper TDA layers, the laboratory compression curves overestimate the computed strain in the field.

Conclusion

Stress-strain was computed in the field using data collected from settlement plates and earth pressure cells embedded in the OTR and PLTT sections. Moreover large-scale, one-dimensional compression tests for the sample with different initial unit weight were conducted to determine the laboratory compression behaviour of OTR and PLTT. Based on the results the following conclusions can be drawn:

- The construction of the test embankment was completed with common construction equipment without any major problems.
- The stress-strain curve from the field data as well as laboratory test showed that TDA become less compressible as strains accumulates and the material strain hardens.
- The data measured using the settlement plate in the field indicated OTR was less compressible than PLTT.

- The compression behavior of both OTR and PLTT in the laboratory depends on the initial unit weight of the sample and stress level. However, there is a general trend of decreasing compressibility as the unit weight of the sample increases.
- As it was observed in the field higher compacted density was achieved in the laboratory for OTR compared to PLTT.
- For PLTT, the laboratory compression curve with initial unit weight 6 kN/m^3 overestimate strain measured in the field for this study.

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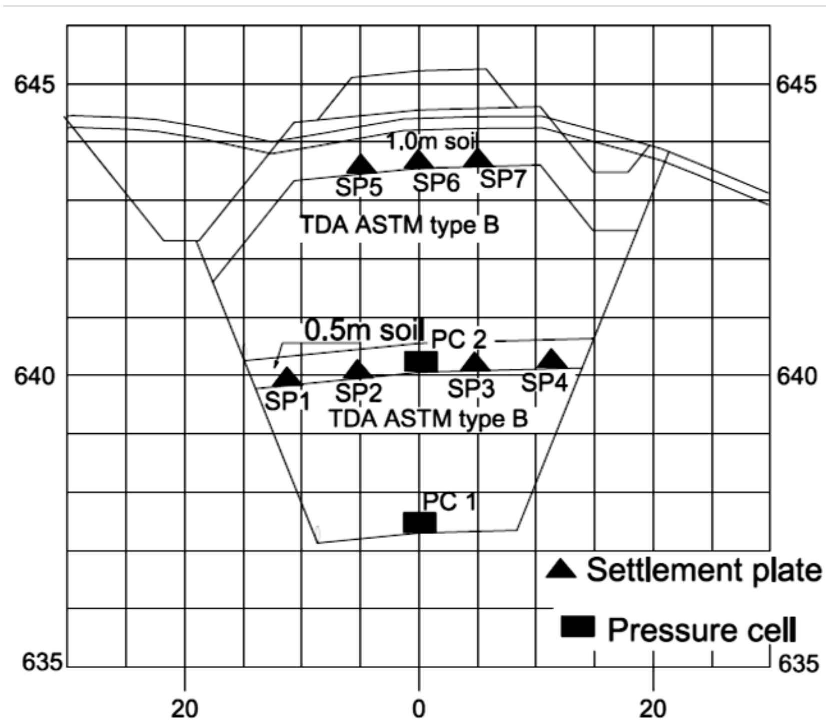


Figure 1 Typical cross section and instrumentation layout for the test embankment (all units in meters).

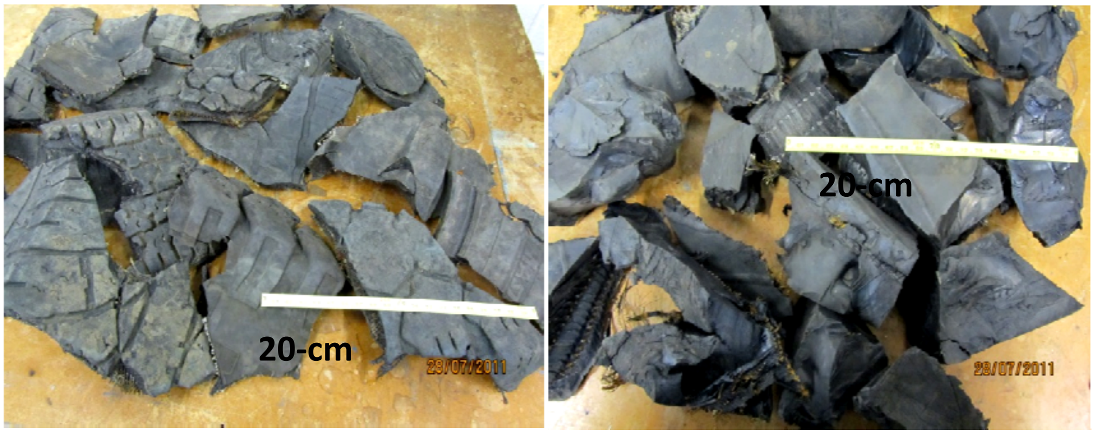
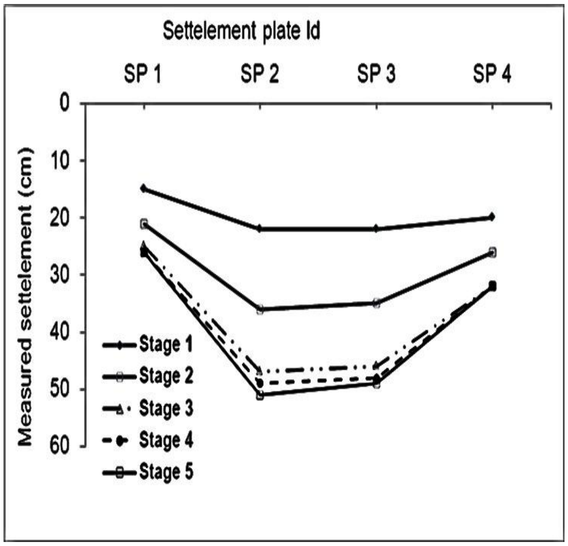
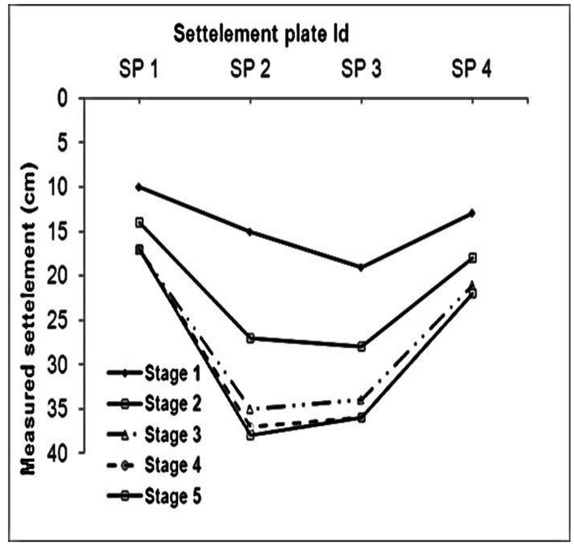


Figure 2 Pictures of PLTT (left) and OTR (right) used in the project.

Figure 3 Picture of the test embankment during construction and instrumentation.



(a)



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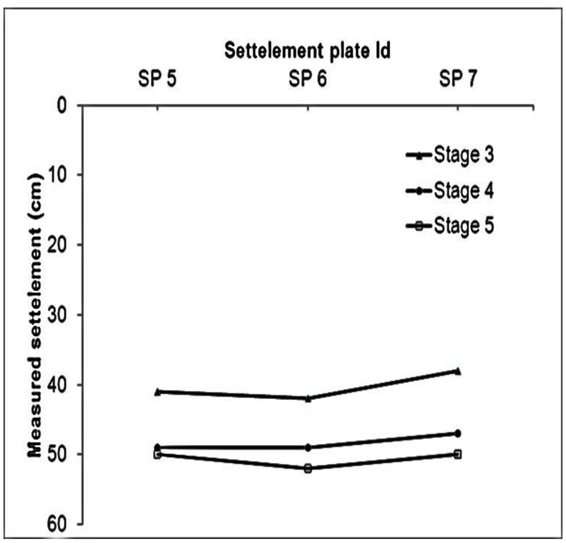
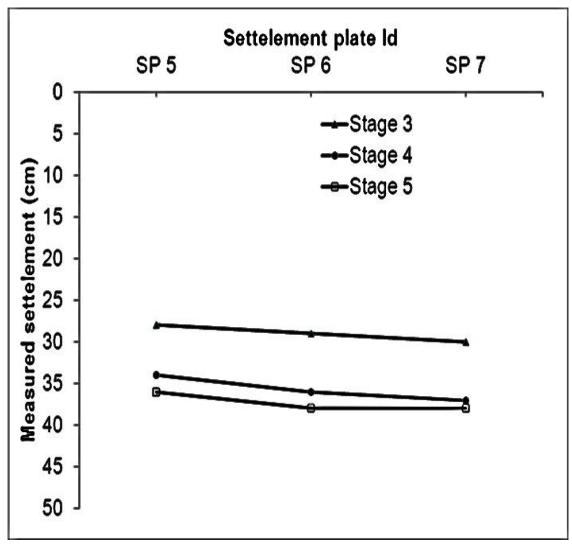


(c)



(d)

Figure 4 Settlement measured at various stages of construction from the settlement plate (a) PLTT lower TDA layer (b) OTR lower TDA layer (c) PLTT upper TDA layer (d) OTR upper TDA layer.

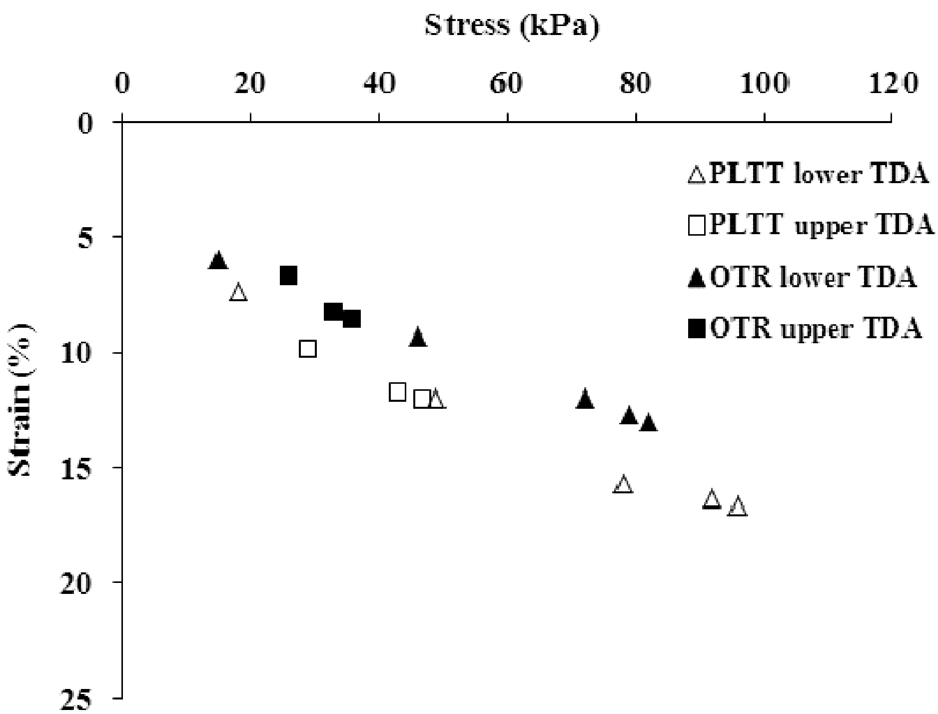


Figure 5 Stress-strain behaviour from field measurements for PLTT and OTR.

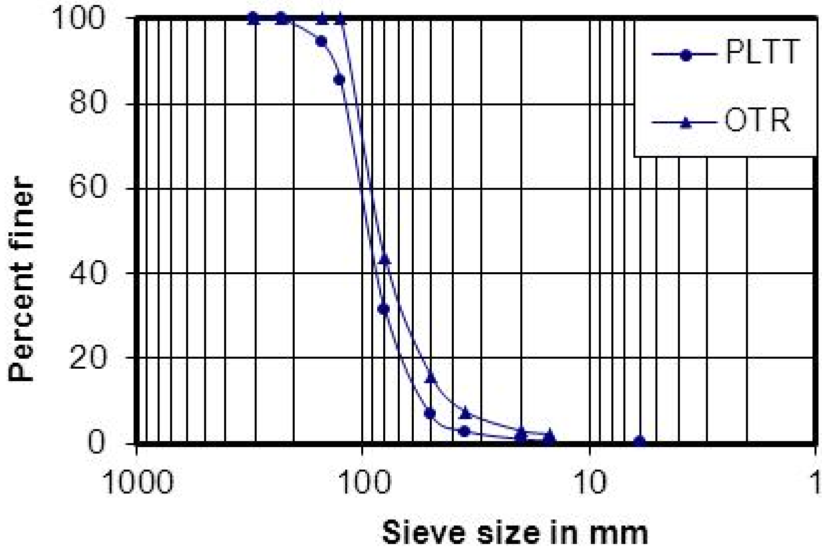
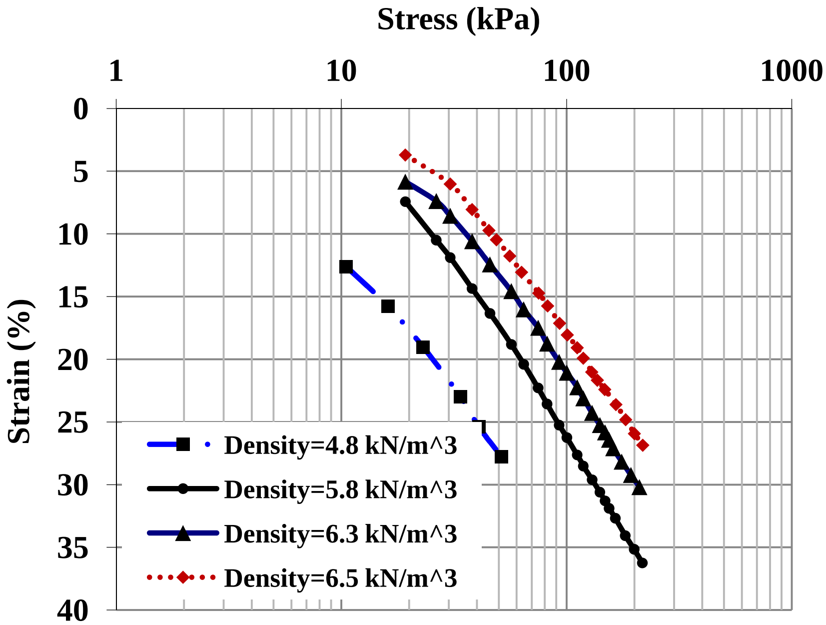
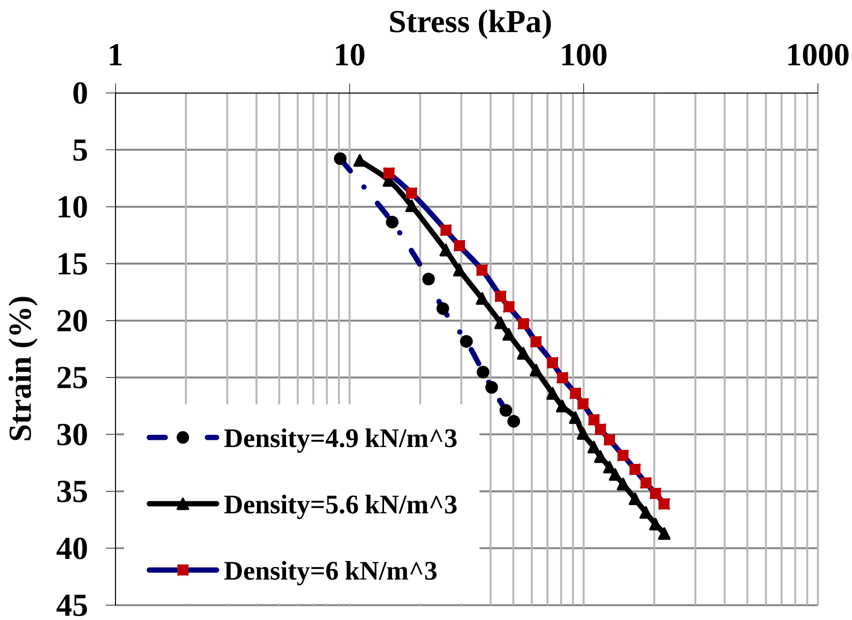


Figure 6 Particle size distribution of TDA sample used for the laboratory test

Figure 7 Photograph of compression apparatus for Testing TDA

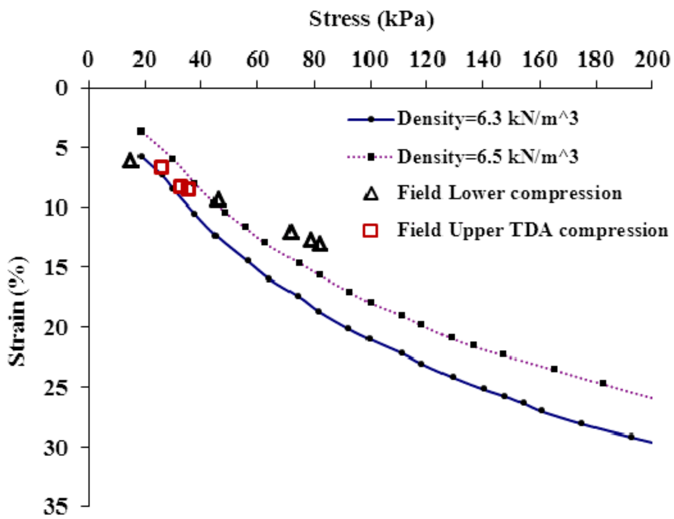


(a)



(b)

Figure 8 Stress strain curve from one dimensional compression test for different initial unit weight of the sample (a) OTR (b) PLTT



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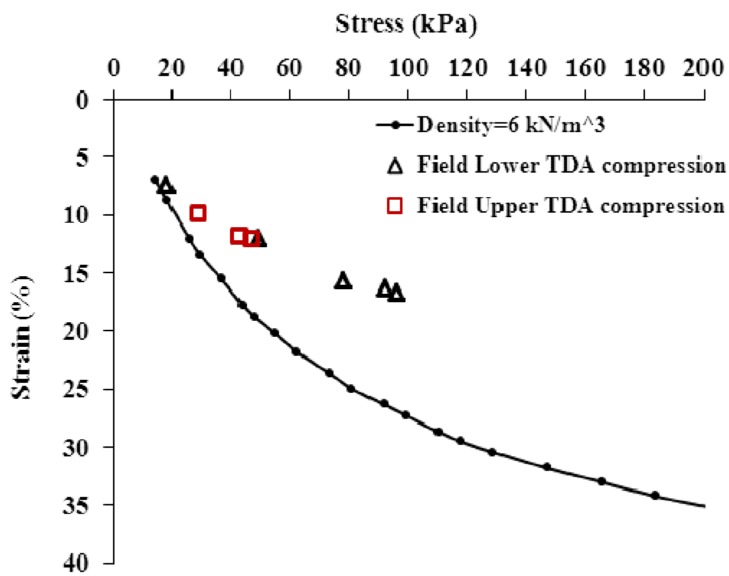

(b)

Figure 9 Comparison of stress strain from large scale laboratory test and field measurement (a) OTR, (b) PLTT