

Long-Term Performance Monitoring of a Recycled Tire Embankment in Wilmington, Delaware

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**LONG-TERM PERFORMANCE MONITORING OF A RECYCLED
TIRE
EMBANKMENT IN WILMINGTON, DELAWARE**

Final Report

to the

Delaware Department of Transportation

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by

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1. Problem Statement

In the United States over 281 million “scrap” tires are discarded annually, and it is estimated that well over 500 million scrap tires are currently being stored in open stock piles (Rubber Manufacturer’s Association, 2005). In the state of Delaware, about 780,000 scrap tires are generated each year and there are currently 38 known stockpiles. The creation of open tire piles is extremely undesirable because the open spaces between tires provides an ideal breeding ground for rodents and mosquitoes, and large tire piles are vulnerable to fire from lightning strikes, arson, or spontaneous self ignition. To avoid tire piling, approximately 50 million used tires are discarded annually into landfills (Garga and O’Shaughnessy, 2000). However, as available landfill space dwindles across the country, it is recognized that this is not a viable long-term solution for disposal of scrap tire materials.

A long-term scrap tire management program is needed for the state of Delaware. At present, it appears that the two most sustainable approaches to tire disposal are burning tires or tire derived fuel (TDF) in tire-to-energy conversion facilities, or recycling tire materials for use in other applications. As of 2005, approximately 20% of the scrap tires that are being re-used or recycled nationwide are being utilized in various civil engineering and construction applications (Rubber Manufacturer’s Association, 2005). Re-use of scrap tires as part of new construction projects presents a significant opportunity for the Delaware Department of Transportation (DelDOT) to aid the State of Delaware as it develops a sustainable scrap tire management program.

2. Summary of Past Work

As a first step towards developing a sustainable solution to the problem of scrap tire generation within the state of Delaware, DelDOT has constructed two test embankments containing recycled scrap tire shreds as part of the abutments for bridge 1-609B on 6th Street in Wilmington, DE. Delaware Center for Transportation (DCT) researchers have been collaborating with DelDOT to monitor the construction of this embankment and to install instrumentation that can be used for long-term physical and environmental monitoring of the structure. Aderinlewo (2006) summarizes the instrumentation plan used to monitor the performance of bridge 1-609B.

Section 5 graphically summarizes the construction of the abutments for bridge 1-609B. The goal of this section is only to provide an overview of the construction process. Further details pertaining to this subject are found in the report by Aderinlewo (2006), and in internal DelDOT reports.

3. Scope of Present Research

The objectives of the present research program are as follows:

1. Survey the literature to see what material characteristics have been observed for mixtures of soil and tire shreds by other investigators. This literature will then be evaluated to develop guidance for how the behavior of scrap tire mixtures can be predicted as part of the design process for new construction.
2. Continue monitoring the settlement plates, lateral pressure transducers and leachate pans installed at the test embankments in Wilmington, Delaware as part of the previously sponsored DeIDOT project.
3. Perform a finite element analysis of a model of the embankment constructed in Wilmington, Delaware as part of the previously sponsored DeIDOT project. Computer results will be compared with the values measured in the field. This will allow DeIDOT to better assess the utility of modeling tools for designing future geotechnical structures constructed using mixtures of soil and tire shreds.
4. Perform statistical analysis of the recorded movement data and other physical monitoring data.
5. Perform long-term compression tests on representative mixtures of soil and scrap tire-shreds obtained from a local tire shredder to develop a better understanding of the long-term compressibility associated with embankment fills constructed out of locally generated scrap tire materials.

4. Summary of Research Findings

The status of each of the above objectives is summarized below.

- With the exception of pertinent references that may appear in the near future, the survey of the literature is complete. It has been determined that the mechanical properties of shredded tire-soil mixtures largely depend on the volume of tire shreds present in the specimen. Further details pertaining to the literature survey are given in Section 6.
- The settlement plates were paved over during the completion of the roadway on both of the abutments for bridge 1-609B. As such, they could no longer be read.
- Readings from the lateral pressure transducers have showed negligible changes in the pressure since construction of the abutments. Visual inspections of the roadway and abutments indicated no distress in either system. Further details pertaining to the lateral pressure measurements are given in Section 7.
- Environmental monitoring, which involved taking specimens from drip pans and measuring concentrations of 15 different elements in the leachate, showed zinc concentrations that exceeded chronic fresh water criteria initially, but decreased through time. Other elements were found to be at acceptable concentrations. The pH of leachate was found to be in the range 6.4-6.6. Further details pertaining to the environmental testing program are given in Section 8.
- Since the settlement plates were paved over during the completion of the roadway, there was no way in which to rationally verify the proposed finite element analyses of the abutments. As such, this objective could not be met.
- The results of the statistical analysis of recorded movement data and other physical monitoring data have not been completed. As such, they are *not* included in this draft report.
- The loading frame required to perform the long-term compression tests on representative mixtures of soil and scrap tire-shreds has been ordered. Once installed, the aforementioned test shall be performed. As such, these results are obviously *not* included in this draft report.

5. Construction of Abutments for Bridge 1-609B: An Overview

Bridge 1-609B carries 6th Street over the CSX tracks in Wilmington, Delaware (Figure 5.1).



Figure 5.1 Picture of Bridge 1-609M in 2010.

The first step in the construction of the abutments for Bridge 1-609B involved the removal of the existing backfill material (Figure 5.2).



Figure 5.2 Excavation of Rear Face of North Abutment

After the excavation process was completed, polymeric material was spread over the excavations (Figure 5.3). The tire-derived aggregate (TDA) was next dumped in both abutment excavations and compacted (Figure 5.4). The presence of leachate pans (for environmental monitoring) required special care in spreading the TDA (Figure 5.5).



Figure 5.3 Polymeric Material in Excavation



Figure 5.4 TDA is Dumped into the Excavations



Figure 5.5 Spreading of TDA in Vicinity of Leachate Pans

6. Summary of Literature Survey

A detailed survey of the literature related to TDA was performed. While the scope of the surveyed papers varied widely, some graphical summaries of findings were made. Figure 6.1 summarizes the effect of rubber (in percent by weight) on the unit weight of soil-tire mixtures. The results presented by Yoon et al. (2006) involved 25 mm or smaller tire particle sizes mixed with poorly graded sand (SP classification). The loose, and lightly compacted soil data of Ghazavi (2004) involved 7 mm or smaller mixed rubber particles mixed with poorly graded sand. The decrease in unit weight realized in going from 0 to 100% of rubber (by weight) is rather dramatic. It is timely to note that the backfill in the Bridge 1-609B abutments consisted of essentially 100% tires.

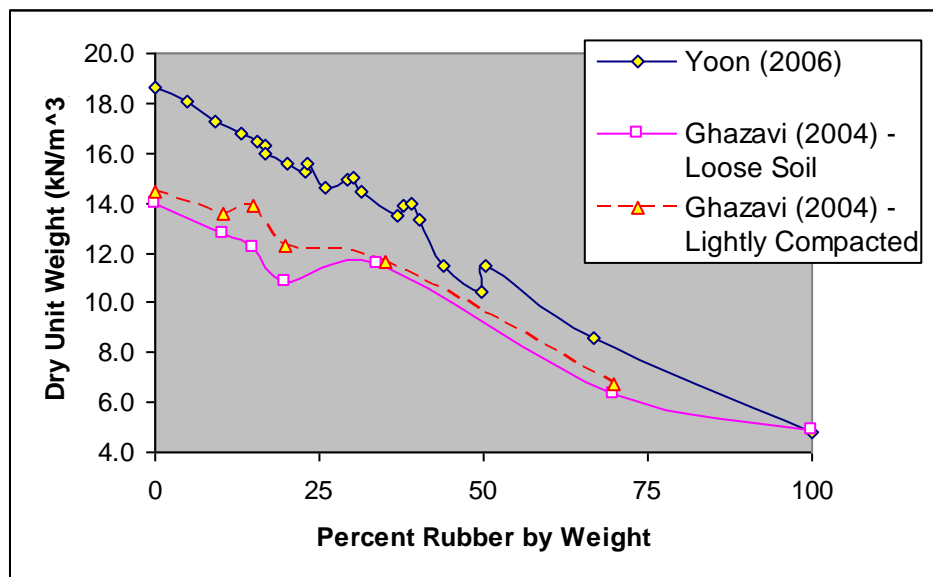


Figure 6.1 Unit Weight of Shredded Tire/Soil Mixtures

Figures 6.2 and 6.3 show the effect of the percent of rubber in a soil/rubber mixture on the initial friction angle. Clearly the friction angle increases with increasing percentages of rubber. However, some of the initial friction angles measured are likely manifestations of using too small of a specimen, resulting in the tire piece spanning the entire width of the specimen.

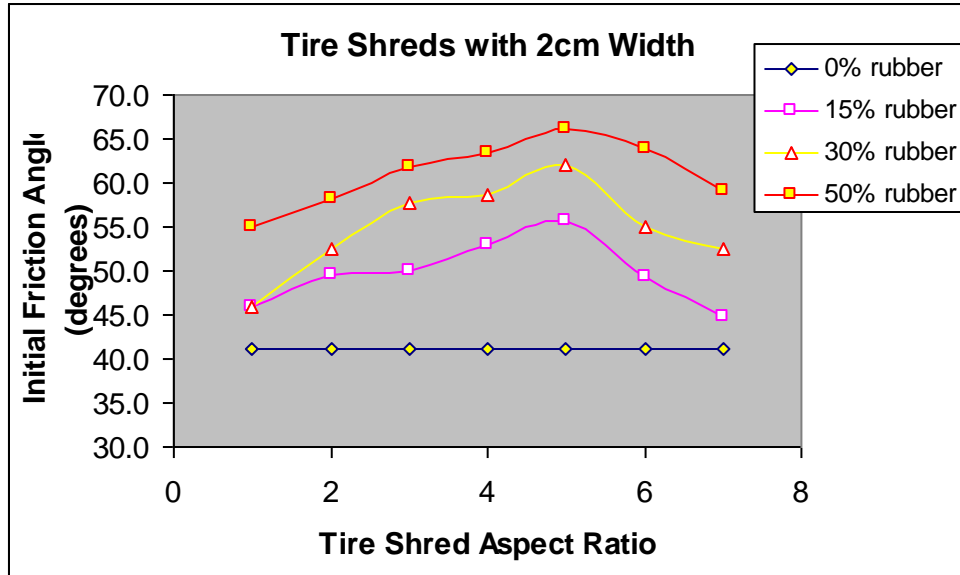


Figure 6.2 Effect of Percentage of Rubber on the Initial Friction Angle of Shredded Tire/Soil Mixtures: $\gamma_m = 16.8 \text{ kN/m}^3$.

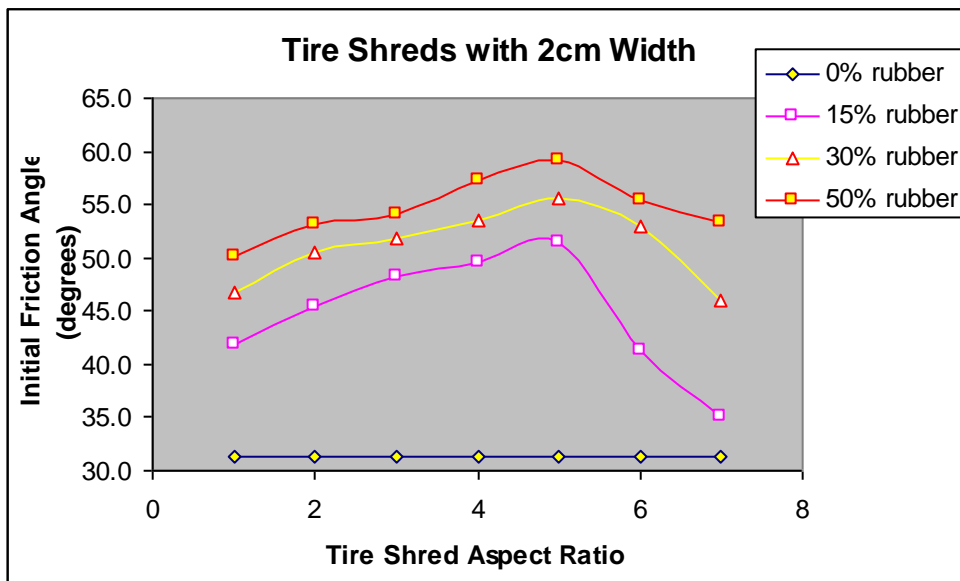


Figure 6.3 Effect of Percentage of Rubber on the Initial Friction Angle of Shredded Tire/Soil Mixtures: $\gamma_m = 15.5 \text{ kN/m}^3$.

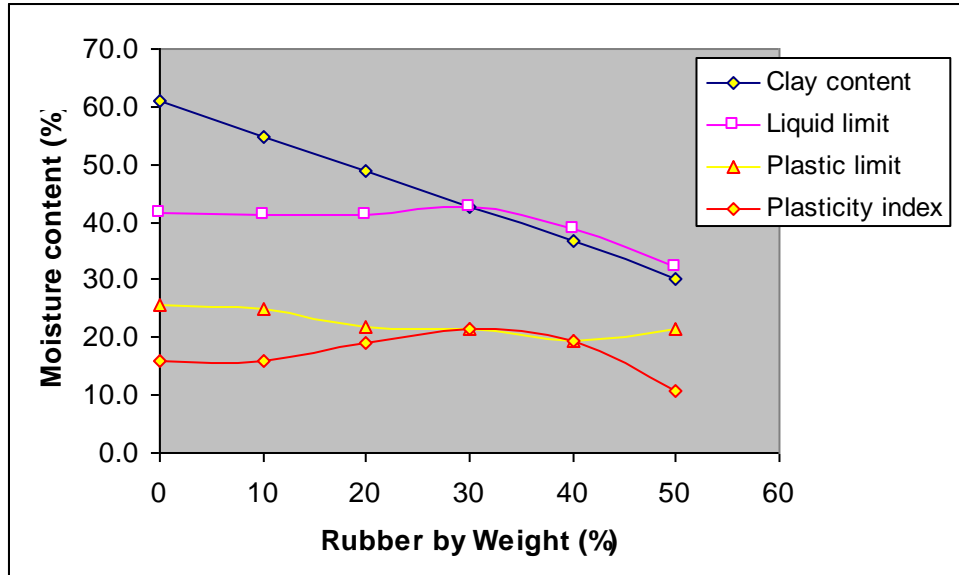


Figure 6.4 Effect of Percentage of Rubber on the Clay Content and Atterberg Limits

Figure 6.4 shows the effect of rubber content on the Atterberg limits and on the clay content. Although these limits decrease somewhat with increase in percentage of rubber, there is seemingly no general trend.

7. Pressure Transducer Readings

Although pressure transducers that measure lateral pressure on the abutment walls were successfully installed, the calibrations factors were lost. As such, the absolute pressures on the abutment walls cannot reliably be determined. The *changes* in pressure with time can, however, be inferred from changes in the pressure time history. As seen from Figure 7.1, the changes in pressure on the abutment walls with time are negligible. This implies that no detrimental effects due to potential settlement of the TDA have been detected.

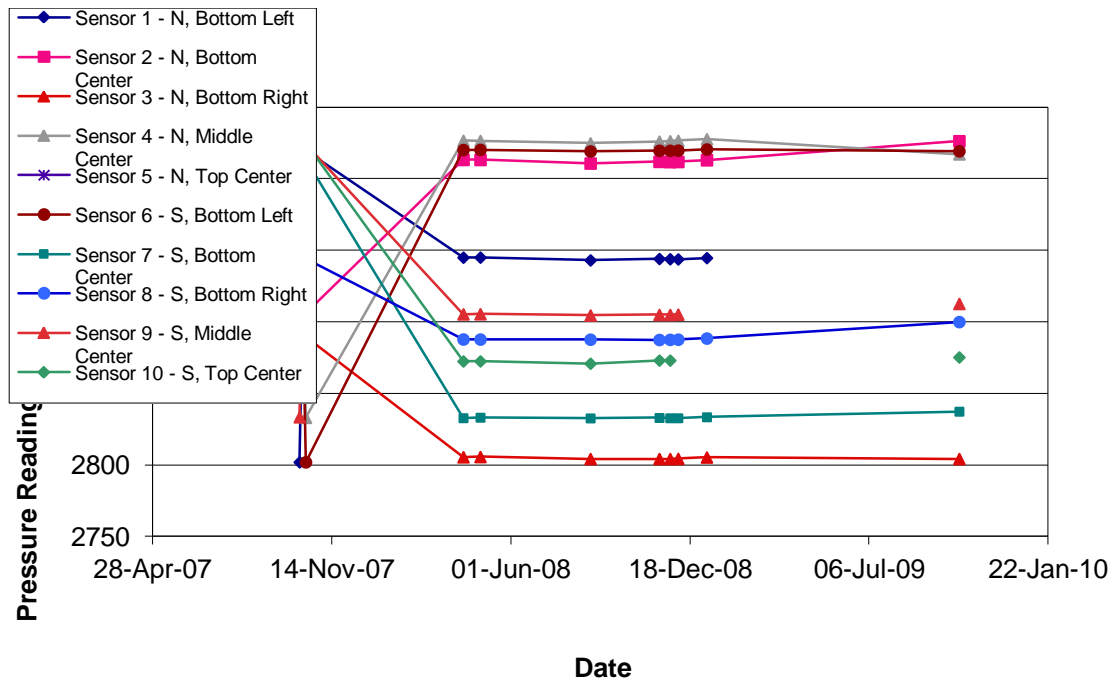


Figure 7.1 Lateral Pressure Readings on Abutment Walls

8. Environmental Testing Program

8.1 Methods

The major environmental concern from use of scrap tire pieces in roadway embankments is the leaching of constituents from the scrap tires. Work by Humphrey and Katz (2000) and Shalaby and Khan (2005) suggests that metals (Ba, Ca, Cr, Cu, Pb, Se, Mn, Na, Fe, and Zn) may leach from scrap tires in quantities sufficient to elevate ground water concentrations. For Fe and Mn, levels were detected that exceeded secondary drinking water standards (Humphrey and Katz, 2000). Because of this past work, metal concentrations were monitored in leachate from the roadway test beds.

Construction of Leachate Collection Basins

Three leachate basins were constructed and then installed in the each test embankments: three in the North Embankment and three in the South Embankment. The leachate basins were constructed of 1/2-inch thick PVC sheets and had a 3-foot square bottom and 6-inch tall sides. The basins were watertight except for a 1/2-inch diameter pipe outlet that was positioned at the bottom to drain all liquid from the basin into the pipe. Pipe extended from each basin through an outlet port drilled through the stone embankment wall. An exposed shutoff valve was installed at the end of each pipe, and each pipe was sloped to allow gravity drainage. The pipe and fittings were PVC and met the requirements of ASTM D1784 and D1785, schedule 40.

Figure 8.1 is a photograph of one leachate basin. Figure 8.2 illustrates the placement of the two of the basins at the bottom of the South embankment. Figure 8.3 shows the emplacement of tire shreds on top of the leachate collection basins in the South Embankment.



Figure 8.1. Photograph of leachate collection basin and PVC pipe that drained leachate.



Figure 8.2. Photograph of two of the three leachate basins installed at the bottom of the South Embankment.



Figure 8.3. Placement of tire shreds on top of a leachate collection basin.

Sampling and Chemical Analyses

Sampling of the leachate in the basins was conducted as follows.

1) Day 1.

Upon arrival at the site, access the ports on the South Embankment first. The sampling ports/valves were kept open between sampling events. Close the ports. Go across the rail tracks to access the North Embankment and close these valves.

2) Day 2.

Open the plastic valve on each port and let it drain for 30 seconds to ensure that the leachate collected in the pipe/conduit connecting the leachate containers to the port is flushed out. Collect the subsequent leachate from the port into a 250 mL plastic sampling bottle. Close the port and store the bottle.

The pH of each sample was analyzed at the University of Delaware. Samples collected in 2007 and 2008 were analyzed for total metal concentrations (non-filtered) using inductively coupled plasma – optical emission spectroscopy (ICP).

8.2 Sampling and Chemical Analyses for Samples Collected in 2009, 2010, and 2011

Sometime in late 2008 or early 2009, valves on the sampling ports were broken off. Thus, rainwater that percolated through the embankment and collected in the leachate collection basins freely drained out of the ports. In this case, it was not necessary to collect samples over a two-day period. While this simplified the sampling, because water collected very slowly in ports 3-6 it was impossible to collect sufficient water from these ports for analysis. Thus, the procedure followed below was used for only ports 1 and 2.

- Collect leachate from the port into a 250 mL plastic sampling bottle.
- Close the port and store the bottle.

The pH of each sample was analyzed at the University of Delaware. Samples collected in 2009 were then acidified to a pH of 1.5 and stored. Samples collected in 2010 and 2011 were not acidified, but were stored for further analysis. All samples were analyzed in the fall of 2011 for total metal concentrations (non-filtered) by the University of Delaware Soil Testing Laboratory in the College of Agriculture and Natural Resources using inductively coupled plasma – optical emission spectroscopy (ICP). These samples were analyzed for Ca, Cu, Fe, Mg, Mn, and Zn. While this suite of compounds is smaller than that analyzed in 2007 and 2008, because elevated metal concentrations were only observed for Fe and Zn in 2007 and 2008 this smaller subset of analysis that included these two metals was deemed adequate.

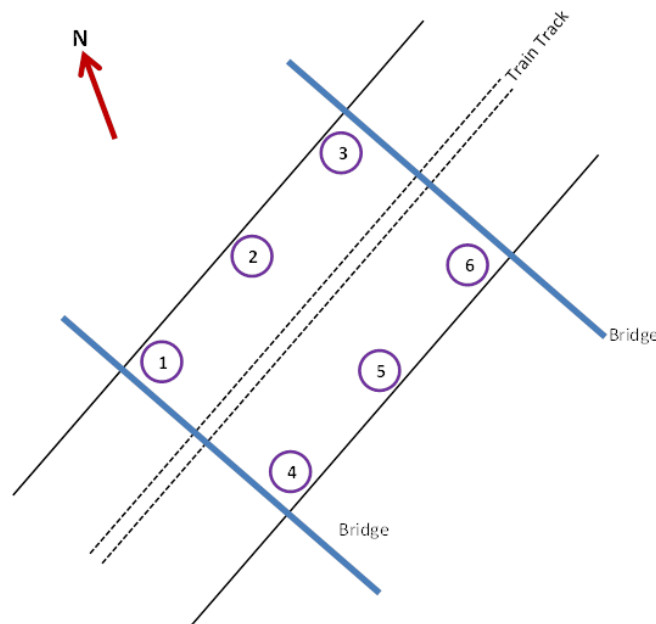


Figure 8.4. Plan view showing the location of the sampling ports on the north and south abutments.

8.3 Results

Table 8.1 lists the elements analyzed in the samples, the Federal acute and chronic water quality limits, and the drinking water limits. Limits are not established for many of the elements listed.

Element	Federal Acute Criteria (FAC) [µg/L]	Federal Chronic Criteria (FCC) [µg/L]	Drinking Water Criteria (DWC) [µg/L]	Category	Source
Ba			1,000	Non-priority	Goldbook ¹
Be	-	-	4	Priority	
Ca	-	-	-	Non-priority	
Cd	2	0.25	5		40 CFR 141 ³
Co	-	-	-	Not Listed	304(a) CWA ²
Cr	570	74	100		
Cu	13	9	1300	Priority	304(a) CWA ²
Fe		1000	300	Non-priority	304(a) CWA ²
Mg				Not Listed	304(a) CWA ²
Mn	-	-	50	Non-priority	
Ni	470	52	610	Priority	
Se		5	50		304(a) CWA ²
V					
Zn	120	120	7400	Priority	
Si	-	-	-	Not Listed	304(a) CWA ²

¹ TheGold Book, Quality Criteria for Water, 1986.

² 304(a) Clean Water Act, USEPA, Current National Recommended Water Quality Criteria

³ 40 CFR 141, National Revised Primary Drinking Water Regulations

Fe Concentrations

Of the elements analyzed, the only two that were frequently higher than the water quality or drinking water limits were Fe and Zn. Concentrations of Fe are shown for samples taken from the North and South Embankments in Figures 8.5 and 8.6, respectively. Results are plotted for two ports on each embankment, labeled West and East. These correspond to ports 1 and 2 on the North Embankment, and ports 4 and 5 on the South Embankment. Only at these ports was sufficient leachate collected to allow for sample analyses.

For the North Embankment, Fe concentrations are frequently above 10 mg/L. Sample concentrations generally decreased with time and were below the detection limit in May 2008. However, samples collected in 2009 were again elevated and above 10 mg/L. The reason for the variability in sample concentrations is unknown but is undoubtedly associated with nonuniform water infiltration in the embankment. The pH of the leachate for all samples collected ranged between 6.2 and 6.9 over all sampling events for both embankments.

Similar trends are seen for data collected from the South Embankment in Figure 8.6: total Fe concentrations decrease with time and are below the detection limit in May

2008. However, sufficient leachate was not collected in 2009 to measure Fe concentrations. Thus, it is impossible to ascertain if the increase in Fe concentration observed in 2009 for the North Embankment leachate also occurred for the South Embankment. The drinking water limit for Fe is 0.3 mg/L.

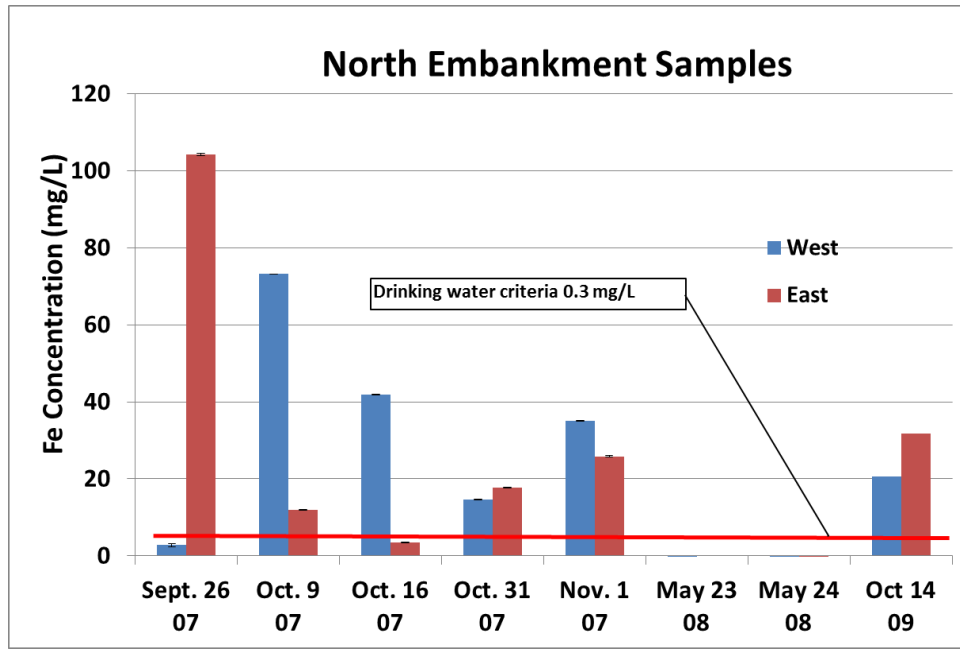


Figure 8.5. Fe concentrations from leachate samples from the North Embankment.

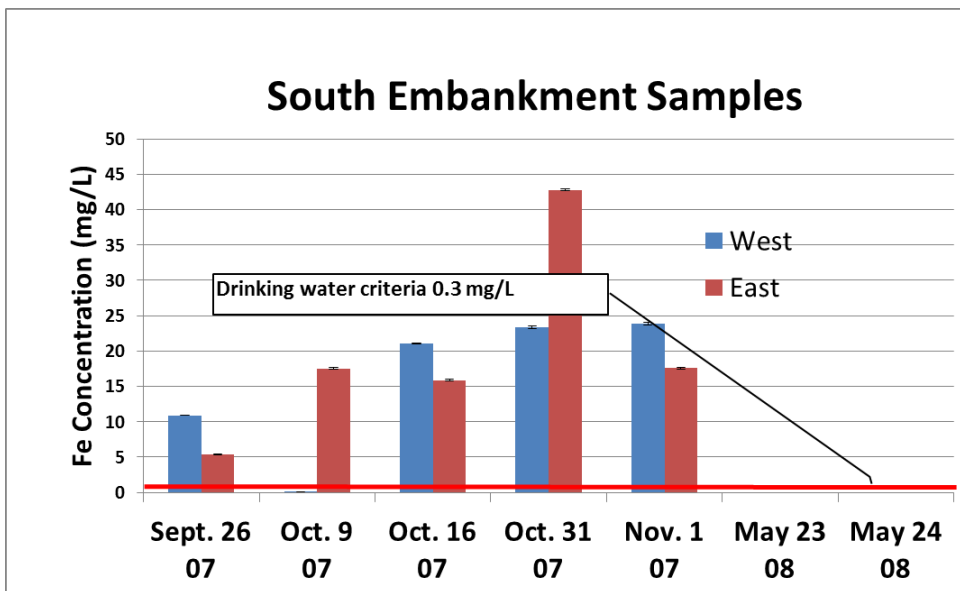


Figure 8.6. Fe concentrations from leachate samples from the South Embankment.

While leachate samples were also collected from ports 1 and 2 in 2010 and 2011, there was an error in sample storage that prevented quantification of total metal concentrations in these samples. Nevertheless, insight into the Fe concentrations in the leachate can be ascertained from photographs of the sampling ports in September 2011. Photographs of sampling ports 1 and 2 are shown in Figures 8.7 and 8.8 and clearly show that Fe concentrations continued to exceed solubility, which resulted in considerable iron oxide precipitating as the Fe-laden leachate contacted oxygen when dripping out of the sampling ports onto the gravel. Thus, even though Fe was not quantified in samples collected in 2010 and 2011, visual observations of the leachate (Port 2 in Figure 8.8) and the ground surrounding each port (e.g., Port 1 in Figure 8.7) indicated that Fe concentrations still exceeded the solubility limit.

Of the six ports in Figure 8.4, the only port where the gravel surrounding the sampling port did not indicate excessive Fe concentrations was Port 5. A photograph of this port is shown in Figure 8.9; no iron oxide precipitate is evident in this photograph.



Figure 8.7. Photograph of Port 1 in September 2011. Note the red iron oxide, indicative of excess Fe in the leachate exiting this port.



Figure 8.8. Photograph of Port 2 in September 2011. Note the red iron oxide on the gravel, and the reddish color of the leachate, also indicative of iron oxide.



Figure 8.9. Photograph of Port 5 in September 2011. The leachate appears clear and there is no evidence of significant iron oxide precipitate on the gravel or abutment wall.

Zn Concentrations

Zn concentrations exceeded water quality criteria (0.12 mg/L) for most sampling events in 2007. Concentrations are shown for the North and South Embankments in Figures 8.10 and 8.11, respectively. However, just as for the Fe measurements, concentrations decreased in 2008 and 2009 and were below water quality criteria from the North Embankment for samples collected in both years. For the South Embankment, sufficient leachate was not collected in 2008 or 2009 to allow for sample analysis. The pH for all samples ranged between 6.2 and 6.9. Because of error in sample storage for samples collected in 2010 and 2011, Zn concentrations could not be quantified in leachate for these measurement periods.

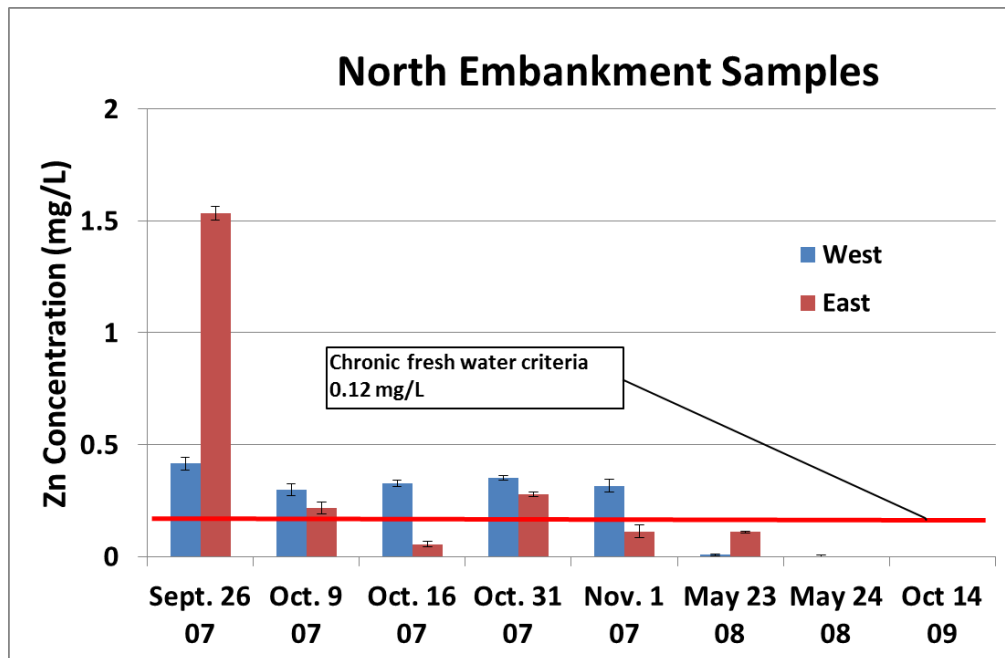


Figure 8.10. Zn concentrations from leachate samples from the North Embankment.

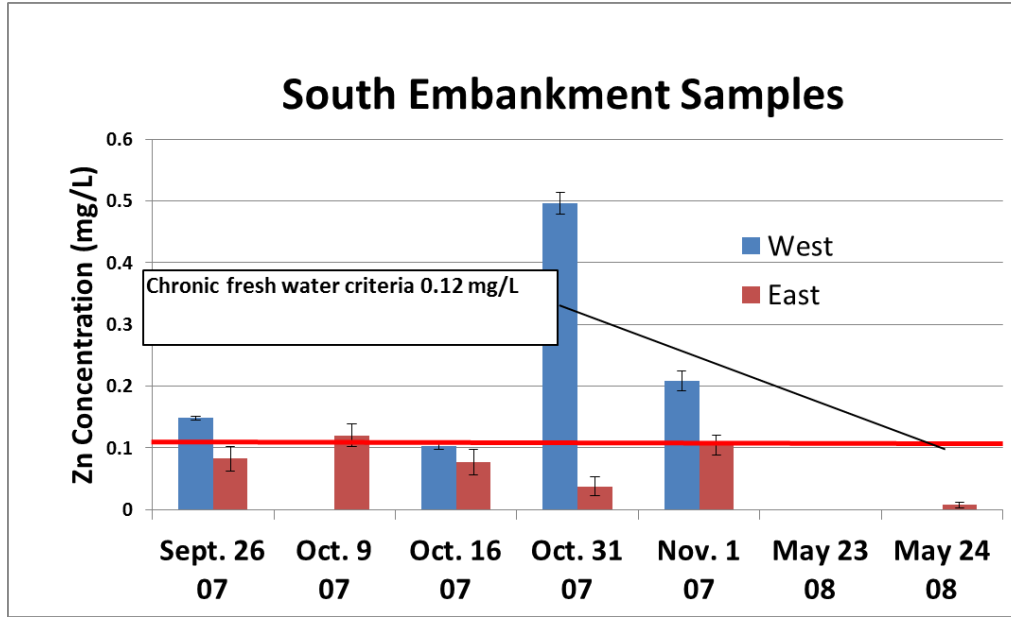


Figure 8.11. Zn concentrations from leachate samples from the South Embankment.

8.4 Discussion

The sampling reported 2007-2011 indicates that elevated levels of Fe and Zn occurred in the leachate from the scrap tire embankment. The highest concentrations of these metals occurred in 2007, with concentrations generally decreasing with time. However, even in fall 2011 Fe concentrations were high resulting in the precipitation of iron oxide (see Figures 8.7 and 8.8). While measured concentrations frequently exceeded drinking water (Fe) or water quality (Zn) criteria, these metals would be diluted in the groundwater before they would reach any stream or drinking water supply. Thus, actual metal concentrations in either drinking water supplies or surface/groundwater would likely be much less than those reported here.

Several elements sampled do not have water quality or drinking water criteria. Of these, Mg was observed at relatively high concentrations in the leachate samples. Concentrations of Mg were as large as 30 mg/L in some samples and in 2009 still remained at 15 mg/L.

It is interesting to compare metal leaching observed in this work with that reported in other studies. Numerous investigations examined the leaching of metals and organics from tire particles or tire shreds. One example is a study by Sheehan et al. (2006), where leaching from tire shreds was studied from a roadway embankment. Here, tire shreds were placed both above and below the water table, and metal concentrations were measured in leachate collected in the vadose zone and in the groundwater. Sheehan et al. (2006) also installed controls to quantify metal concentrations in embankment soils without tire shreds. Sheehan et al. (2006) found metal concentrations were elevated above background control levels only when the tire shreds were immersed in groundwater below the water table. In this case, groundwater concentrations of Fe, for example, were

as high as 80 mg/L. This is in the range of the highest Fe concentrations measured in this study (~100 mg/L). However, elevated Fe concentrations were observed in leachate from the *vadose zone* in this study. Similar high concentrations of Fe were not observed in vadose zone samples collected by Sheehan et al. (2006).

Despite elevated Fe concentrations measured in their work, Sheehan et al. (2006) concluded that dilution caused by advection and dispersion of groundwater could reduce Fe concentrations sufficiently such that concentrations were no longer toxic. In this case, any downgradient receptor (e.g., groundwater well) must be sufficiently far from the leachate source for concentrations to decrease to nontoxic levels.

Based on the modeling and analysis in the Sheehan et al. (2006) work, we anticipate similar results for metal concentrations leaching from the shredded tires in this study. While local leachate concentrations are high and likely toxic to some biota, groundwater concentrations will decrease significantly for distances on the order of 10 m away from the site.

9. Laboratory Testing Program

9.1 General Comments

This chapter describes the laboratory equipment used to perform tests on shredded tire samples, as well as some typical results obtained in these tests. Because of delays in procuring the equipment, additional testing of such samples is still ongoing. Consequently, in the future additional results will be provided, when appropriate, in the form of a supplemental report.

9.2 Testing Equipment

All tests were performed using a Geotac large triaxial testing frame/cell in conjunction with a 10,000 lb load cell. A linear position sensor, with a range of three inches was used, as were two pressure sensors with a range of -14 psi to 190 psi.

9.3 Material Tested

The material used were tire chips smaller than one inch in size. Tire chips were sieved to ensure that all particles were indeed smaller than one inch in size. Figure 9.1 shows some typical tire chips before sieving.

Prior to testing, all steel belting was manually removed to prevent destruction of the membrane during testing and to simulate conditions in which the belting had corroded away in situ, thus removing any “cohesive” effect that it may have had.



Figure 9.1. Shredded tire chips before sieving.

9.4 Testing Procedure

Samples were prepared to a unit weight of 47 pcf by placing six lifts of 1.53 lbs and compacting them in a PVC forming jacket to a height of 2 inches. Figure 9.2 shows one-half of the forming jacket; the height of the six lifts is evident from the lines made with a black marker. Figure 9.3 shows the entire forming jacket.

The above process created a sample that was 12 inches in height and had a diameter of 6 inches. Samples were then sealed with three o-rings on both the top and bottom platens (Figure 9.4). A vacuum of approximately 5 psi was placed on the samples to help them retain their rigidity while moving them to the Trautwein large capacity triaxial testing device (Figure 9.5).

The lowest unit weight obtained was 37 pcf. This was achieved by simply dropping the particles into the forming jacket without compaction and weighing the contents. The highest unit weight given in the literature was 47 pcf. This value was attained in the present work by compacting in 2 inch lifts using a proctor hammer and about 30 blows per lift.

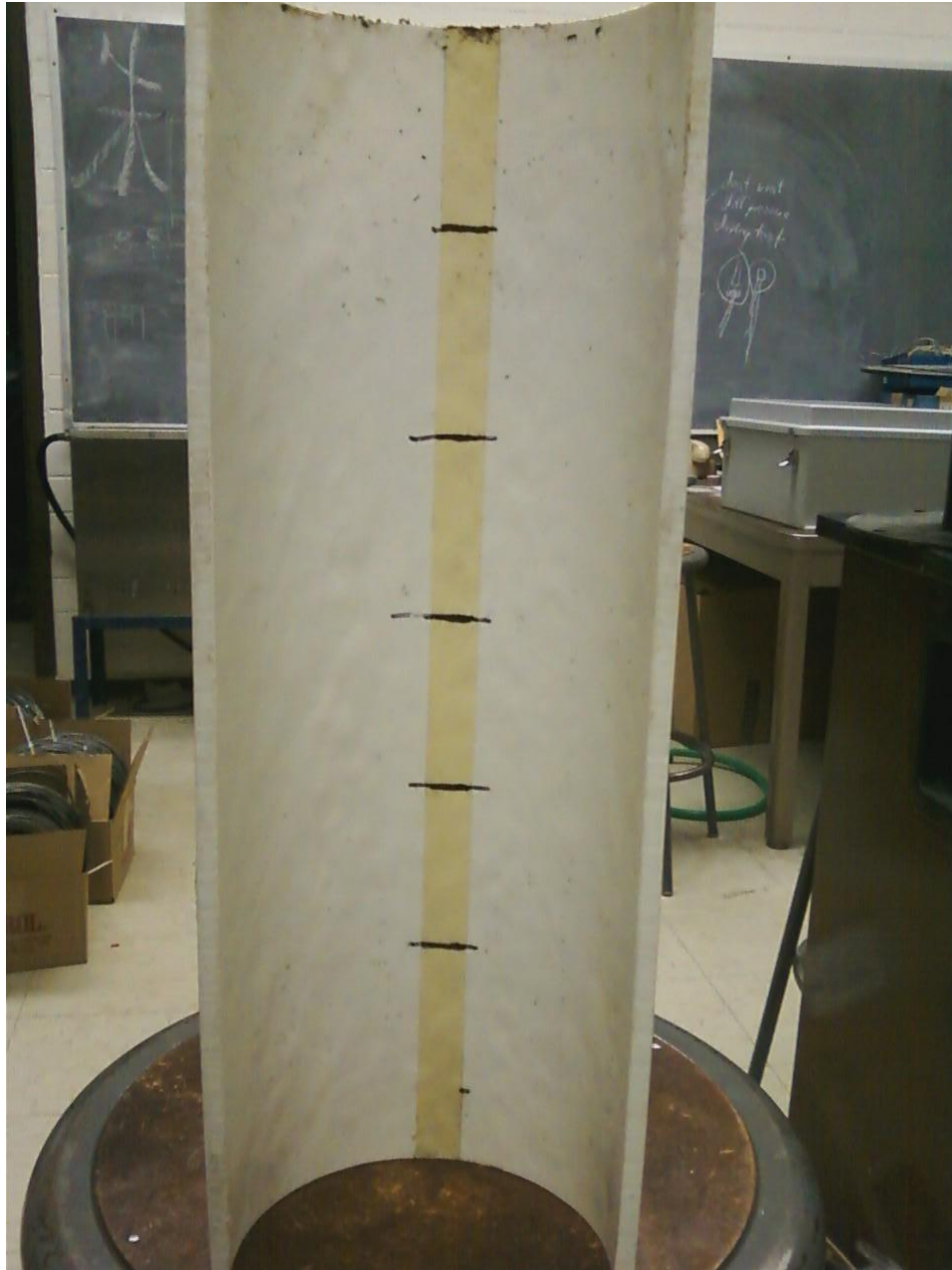


Figure 9.2. One-half of the PVC forming jacket. Black lines denote lift thicknesses.



Figure 9.3. PVC forming jacket connected to base.

Samples were then tested using a consolidated undrained (CU) triaxial testing procedure in general accordance with ASTM standard test method D4767-11. Failure was defined by the maximum deviatoric stress, which in all cases occurred at approximately 15% axial strain. Figures 9.6. and 9.7 show typical samples at failure.

Because the membrane correction was less than 5% of the deviatoric stress for all tests, no membrane correction was used.



Figure 9.4. Typical sample encased in rubber membrane and sealed with o-rings.



Figure 9.5. Typical sample large capacity triaxial testing device.



Figure 9.6. Failed sample at 6.5 psi confinement pressure.



Figure 9.7. Failed sample at 23.0 psi confinement pressure.

9.5 Typical Results

Samples were assumed to have no cohesion and as such the failure envelope was forced to pass through the origin during the analysis. Figure 9.8 shows a typical effective stress failure envelope.

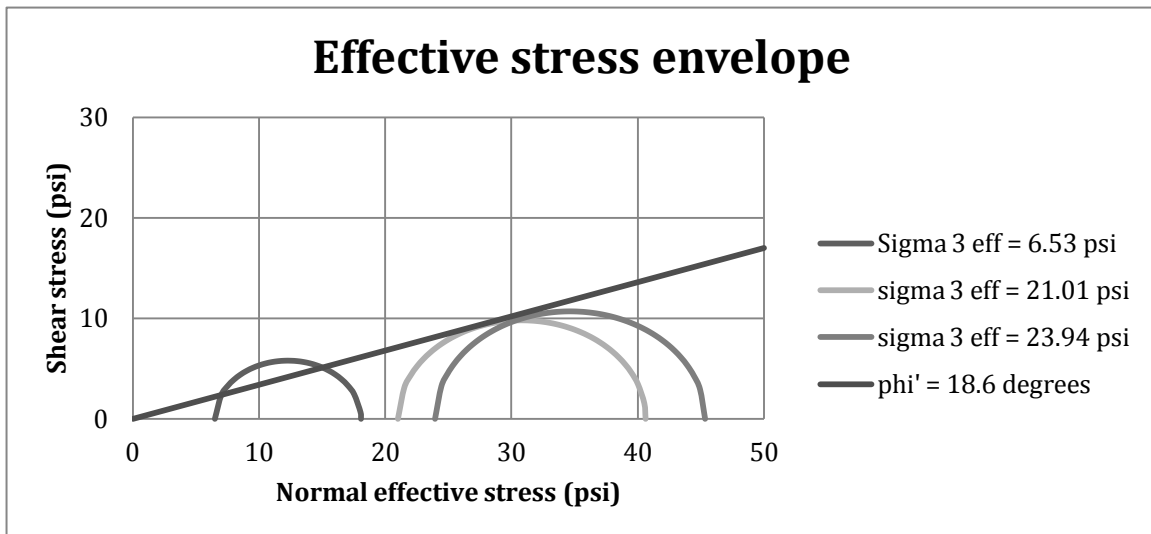


Figure 9.8. Typical effective stress failure envelope.

The friction angles obtained were at the low end of what is listed in the literature. This is likely due to the removal of the steel belting. In addition, many of the previous studies described in the literature used larger particles as compared to those tested in the present project.

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