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16. Abstract

According to recent research, it is estimated that there are more than 500 million tires stockpiled across the United States, and 270 million more are generated each year. A significant number of tires are left in empty yards and even dumped illegally. Tires have characteristics that make them not easy to dispose, and potentially combustible. For these reasons, there is a strong need to find beneficial ways to recycle or reuse tires. Civil engineering applications constitute one of biggest markets for scrap tires. Tire shreds can be used as fill material, for example.

The objective of this research is to evaluate the feasibility of using a mixture of tire shreds and soil as fill material for embankments on the basis of field instrumentation and tests. Successful construction and performance of tire shred embankments may promote using tire shred as fill material, with large benefits to society. The present research project consists of construction of test tire shred and soil embankment as well basic laboratory tests for material property characteristics and instrumentation of the embankment. The instrumentation includes settlement monitoring using settlement plates, vertical and horizontal inclinometer monitoring, temperature monitoring and groundwater quality analysis. The performance of the embankment is evaluated based on field instrumentation and visual observation.

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Final Report

FHWA/IN/JTRP-2002/35

CONSTRUCTION OF TIRE SHREDS TEST EMBANKMENT

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Indiana Department of Transportation
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IMPLEMENTATION REPORT

According to recent research, it is estimated that there are more than 500 million tires stockpiled across the United States, and 270 million more are generated each year. A significant number of tires are left in empty yards and even dumped illegally. Tires have characteristics that make them not easy to dispose, and potentially combustible. For these reasons, there is a strong need to find beneficial ways to recycle or reuse tires.

Civil engineering applications, one of the major markets for scrap tires, have been growing steadily for ten years. Tires have been reused in civil engineering applications including leachate collection systems, landfill cover, artificial reefs and clean fills for road embankments.

Tire shreds have several advantages as fill material for embankment or retaining wall backfills due to their unique characteristics. One of the most important properties is that tire shreds are a lightweight material that is relatively inexpensive. Additionally tire shreds induce low horizontal stresses since they are lightweight and have relatively high shear strength. Tire shreds are also free-draining, and thus do not induce excessive pore pressure that can cause stability problems during the loading of fills.

The main goal of this project is to evaluate the feasibility of using tire shred and soil mixtures as fill materials for embankments on the basis of field instrumentation and tests. The present research project consists of construction of an instrumented test tire shred and soil embankment as well as basic laboratory tests.

Results from the laboratory testing and field instrumentation lead to the following conclusions and recommendations:

(1) At State Rd. 31 in Lakeville, IN. a tire shred and soil embankment was constructed. The fill material was a 50/50 mixture by volume of tire shred and soil. The total volume of the embankment after compaction was approximately 813 m^3. The height and length of the embankment were about 2 m and 20 m respectively.

(2) Monitoring using nine settlement plates at three different sections was conducted for a year after opening the road for traffic. The maximum settlement was approximately 12 mm and the settlement stabilized after 200 days of traffic.

(3) Vertical and horizontal inclinometer monitoring was conducted to check lateral movement and differential settlement for one year. Maximum lateral movement was about 5 mm. No evidence of significant differential settlement has been observed.

(4) Samples of groundwater were analyzed for metals which apply to a secondary drinking water standard and standard of maximum contaminant level for drinking water according to Indiana Department of Environmental Management (IDEM). Except for manganese, all levels have been well below the standard limits. However manganese is not a health concern.

(5) To check for the possible development of exothermic reactions that might lead to the initiation of fires in the embankment, the temperature was observed for a year. No evidence of internal heat generation has been detected. This confirms that the use of tire shred and soil mix is a proper way to prevent self-heating of the tire shreds.

(6) Observations show no signs of slope stability problems, cracking on the road or erosion.

(7) Based on the above findings and observations, using a mix of tire shreds and soil in embankments or fills is very promising and should be promoted. Performance of the test embankment was quite satisfactory. Advantages of this material include the fact that it is lightweight, relatively cheap, easy to compact, free-draining and relatively compressible. Additionally, this use is beneficial to the environment in that a waste material is recycled.

(8) Given the characteristics of soil-tire shreds mixer, these mixer can be used as backfill material for retaining structures. Since tire shreds are lightweight, they induce low horizontal stresses thus reducing the thickness of retaining structures. Similar cost savings will be possible for MSE walls as well.

(9) Based on the experience of the construction of the test embankment in this project, a special provision for the embankment constructed of shredded tires and granular fill is provided.

(10) To prevent self-ignition, floating of the tire shred in a soil matrix is desired. The minimum mixing ratio that produces such an arrangement can be determined by vibration compaction tests. The mixing ratio producing a minimum overall void ratio is the minimum mixing ratio leading to this arrangement. Other mixing ratio can be explored in order to increase the strength of other result mixture.

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CHAPTER 1. INTRODUCTION

1.1 Introduction

According to recent research, it is estimated that there are more than 500 million tires stockpiled across the United States, and 270 million more are generated each year (Dickson et al., 2001). About 30% of these tires are disposed in landfills and thousands of tires are left in empty yards and even dumped illegally. In the state of Indiana, approximately 5 million waste tires are generated each year and there are 40 stock piles containing millions of tires in different counties (Kaya, 1992). Tires have characteristics that make them not easy to dispose, and potentially combustible. For these reasons, there is a strong need to find beneficial ways to recycle or reuse tires.

In civil engineering applications, usually tires are used in a shred form referred to as “tire chips”. These chips are between 12 and 50 mm in size and with steel belting removed in processing. Civil engineering applications, one of the major markets for scrap tires, have been growing steadily in a decade. Approximately 12 million scrap tires in 1995 and 15 million in 1996 have been used for civil engineering applications including leachate collection systems, landfill cover, artificial reefs, clean fill for road embankment, road bed support and similar projects (Liu et al., 2000).

Using tire shreds for civil engineering application has several advantages due to their unique characteristics. One of most important properties is that tire shreds are a lightweight material. When roads are constructed across weak and compressible soil, the stability and settlement problems are critical. Several conventional lightweight materials, such as wood-chips or saw dust, have been used to reduce the weight of the highway structures. There are many benefits to use tire shreds as lightweight fill in embankment or retaining wall backfills since tire shreds are non-biodegradable and thus more durable. The cost of tire shred is from $5 to $50 per cubic yard based on the quality of tire shred (Vipulanandan, 1998). It is relatively inexpensive compared to other light fill materials.

Tire shreds induce low horizontal stresses since they are lightweight and have relatively high shear strength. Due to these properties, the thickness of retaining wall can be reduced and construction cost can be saved. Also tire shreds are free draining, and thus do not induce excessive pore pressure that can cause stability problems during the loading of fills. The insulation value of tire shred is seven times higher than that of soil. Thus, tire shred is a good material that can impede frost penetration beneath roads.

Tire shreds as a lightweight fill material have been studied and used in embankment and retaining structure in various states, such as Colorado, Indiana, Maine, Minnesota, Oregon, Vermont, Washington and Wisconsin. More than seventy successful projects have been conducted with tire shred and tire shred/soil mixture fill material across the U.S (Humphrey, 1996).

Seven states, such as North Carolina, Oregon, Minnesota, Washington, Colorado, Indiana, and New York, have some provision for use of tire shreds (H. Moo-young et. al., 2001).

1.2 Project Outline

The present research project consists of the construction of a test tire shred and soil embankment, basic laboratory tests for material property characteristics and field instrumentation of the embankment. The instrumentation includes settlement monitoring using settlement plates, vertical and horizontal inclinometer monitoring, temperature monitoring and ground water quality analysis.

1.3 Research Objective

The goal of this project is to evaluate the feasibility of using a mixture of tire shreds and soil as fill material for embankments on the basis of field instrumentation and tests. Previous projects in Washington and Colorado that experienced exothermic reactions in tire shred fill. Some concerns regarding the use of tire shred as fill material will be addressed and various studied have been conducted to prevent internal heat generation. Mixing of tire shred and soil can be a promising method to prevent self-heating. In addition there is concern about environmental effects, such as contamination of ground water. Successful construction and performance of tire shred embankments may promote using tire shred as fill material with large benefits to society.

CHAPTER 2. ENGINEERING PROPERTIES OF TIRE SHREDS

2.1 Dry Unit Weight

Tire shred is a lightweight material. Table 2.1 shows various unit weights of different types of compacted tire shred. As shown in, the unit weight of compacted tire shred ranges from 2.4 kN/m^3 to 7.0 kN/m^3. These values are approximately half of those of typical soils.

The effect of compaction effort on the unit weight of tire shred and soil mixture decreases as tire shred/soil ratio increase. The effect of compaction energy is small for tire/soil mixture with tires greater than 20% in dry weight (Ahmed, 1993).

2.2 Hydraulic Conductivity

The drainage characteristic of fill material significantly influences on the stability of embankment or retaining structures under saturated conditions. Fill material with low permeability under a saturated condition induces slope failure due to generation of excessive pore pressure. Compacted tire shred has hydraulic conductivity values equivalent to that of typical coarse gravel which ranges from 2.0 cm/s to 0.75 cm/s (Ahmed, 1993)

2.3 Shear Strength

Shear strength is one of the fundamental engineering properties of construction material. Table 2.3 shows shear strength values for different types of tire shred. The shear strength of a tire shred and soil mixture is mainly affected by confining stress and the ratio of tire and soil. In case of a tire shred and sand mixture, tire shred has a reinforcing effect. According to Ahmed (1993), the ratio of tire chip and sand at maximum shear strength is approximately 39% at low to medium confining stress. This is thought to be an optimum ratio for a tire shred and sand mixture for light-weight fill.

2.4 Environmental Properties

As shown in Table 2.4, the principal chemical substances of tires are natural and synthetic rubber that contains inorganic and organic components. Various studies from laboratory tests and field test embankments with tire shred fill material indicate negligible effect on environmental problems such as groundwater quality (Humphrey, 2000).

2.5 Exothermic Reaction in Tire Shred Fills

In 1995 there were three sites that experienced an exothermic reaction inside tire shred fill in Washington (Humphrey, 1996). Ignition can occur due to the rise in temperature from an exothermic reaction. Potential causes of initial exothermic reaction are as follows: (Humphrey, 1996),

1) oxidation of exposed steel wires
2) oxidation of rubber
3) microbes consuming liquid petroleum products.

According to ASTM D6270-98, design guide lines are given to minimize the possibility for heating of tire shred fills for Class I fills, with tire shred layer less than 1m thickness, and Class II fills, with tire shred layers in the range of 1m to 3m thick, as follows;

1) For both Class I and II Fills, the tire shred shall be free of all contaminants, such as oil, grease, gasoline, diesel fuel, etc., that could create a fire hazard.
2) For Class I Fills, the tire shred shall have a maximum of 50% (by weight) passing the 38mm sieve and a maximum of 5 % (by weight) passing the 4.75mm sieve.
3) For Class II Fills, the tire shred shall have a maximum of 25% (by weight) passing the 38mm sieve and a maximum of 1 % (by weight) passing the 4.75mm sieve. The tire shred shall be free from fibrous organic matter. The tire shred shall have less than 1% (by weight) of metal fragments.
4) Class II Fills shall be constructed in such a way that infiltration of water and air is minimized.
5) For Class II Fills, use of drainage features located at the bottom of the fill that could provide free access to air should be avoided.

Table 2.1 Dry Unit Weight of Different Types of Compacted Tire Shreds

(after Reddy and Marella, 2001)

Reference	Tire shred size (cm)	Dry unit weight (kN/m^3)	Compaction type
Ahmed, 1993, Ahmed and Lovell, 1993	1.3-2.5	4.90	ASTM D 4253
	1.3	4.67	ASTM D 4253
	1.3-5.1	6.07	50% Standard
	1.3-2.5	6.29	50% Standard
	1.0-5.1	6.29	Standard
	1.3-3.8	6.38	Standard
	1.3-2.5	6.45	Standard
	2.3	6.26	Standard
	1.27-5.1	6.56	Modified
	1.3-2.5	6.71	Modified
Humphrey et al., 1992, Humphrey and Sandford, 1993	0.2-7.6	6.13	60% Standard
	0.2-5.1	6.29	60% Standard
	0.2-2.5	2.4	60% Standard
Tweedie et al., 1998	3.8-	6.96	Full scale field test
	7.6	6.78	Full scale field test

Table 2.2 Hydraulic Conductivity of Different Types of Tire Shreds

(after Reddy and Marella, 2001)

Reference	Tire shred size (cm)	Hydraulic Conductivity (cm/s)	Test condition
Humphrey et al., 1992, Humphrey and Sandford, 1993	1-5.1	7.7	Void ratio, e=0.925
	1-5.1	2.1	e=0.488
	1.9-7.6	15.4	e=1.114
	1.9-7.6	4.8	e=0.583
	1-3.8	6.9	e=0.833
	1-3.8	1.5	e=0.414
Zimmerman, 1997	20.3-40.6	9.0	e=2.77
	20.3-40.6	3.2	e=1.53
	20.3-40.6	1.8	e=0.78
Lawrence et. al., 1998	1.3-3.8	7.6	e=0.693
	1.3-3.8	1.5	e=0.328
	1.3-7.6	16.3	e=0.857
	1.3-7.6	5.6	e=0.546
Ahmed, 1993 ASTM D6270, 1998	2.5	1.8×10^{-3}	Mix with Ottawa sand, 15.5% of tire shred in weight
	2.5	3.5×10^{-3}	Mix with Ottawa sand, 30.1% of tire shred in weight
	2.5	8.7×10^{-3}	Mix with Ottawa sand, 37.7% of tire shred in weight
	2.5	1.8×10^{-5}	Mix with Crosby till, 14.8% of tire shred in weight
	2.5	2.1×10^{-3}	Mix with Crosby till, 30.1% of tire shred in weight
	2.5	8.8×10^{-3}	Mix with Crosby till, 40% of tire shred in weight
	1.3	9.7×10^{-3}	Mix with Crosby till, 40% of tire shred in weight

Table 2.3 Shear Strength of Different Types of Tire Shreds

(after Reddy and Marella, 2001)

Reference	Tire shred size (cm)	c (kN/m^2)	ϕ (°)	Test condition
Ahmed and Lovell, 1993	1.3	35.8	20.5	Standard compaction & 20% strain as failure
	2.5	39.2	24.6	Modified compaction & 20% strain as failure
	2.5	33.2	25.3	Standard compaction & 20% strain as failure
	2.5	37.3	22.6	50% standard compaction & 20 % strain as failure
Humphery et al., 1993	<3.8	8.6	25	Normal stress : 19.2-71.8 (kN/m^2)
	<5.1	4.3-7.7	21-26	
	<7.6	11.5	19	
Bernal et al., 1996	5.1	0	17-35	17° at 5% strain 35° at 20% strain
Masad et al., 1996	0.46	70.0	6	10% strain
		71.0	11	15% strain
		82.0	15	20% strain
Wu et al., 1997	<0.2	0	45	Triaxial tests under confining pressure of 34.5-55.0 (kN/m^2)
	<0.9	0	47-60	
	<1.9	0	54	
	<3.8	0	57	

Table 2.4 Chemical Composition of Scrap tires

(after H. Moo-young et. al., 2001)

Description	% by weight as received	% by weight, dry basis
Proximate analysis		
Moisture	0.62	-
Ash	4.78	4.81
Volatile Matter	66.64	67.06
Fixed Carbon	27.96	28.13
Total	100	100
Elemental mineral analysis (Oxide form)		
Zinc	1.52	1.53
Calcium	0.378	0.380
Iron	0.321	0.323
Chlorine	0.149	0.150
Chromium	0.0097	0.0098
Fluoride	0.0010	0.0010
Cadmium	0.0006	0.0006
Lead	0.0065	0.0065

CHAPTER 3. CONSTRUCTION OF TIRE SHRED AND SOIL MIXTURE EMBANKMENT

3.1 Project Description

The test site is located at State Rd. 31 in Lakeville, IN. This project is part of a reconstruction project with removal of an old bridge. The tire shred and soil embankment were constructed with an approximate 50/50 volumetric ratio of tire shred and soil as fill material. The total volume of the tire shred and soil embankment after compaction was 813 m^3. The height and length of embankment is approximately 2m and 20m respectively.

3.2 Details of Fill Material

3.2.1 Tire Shred

Tire shred used in this project were produced and supplied by Dillion Tire at North Liberty, IN. Shred tire meeting the requirement for 329 IAC 2-9-3 and described as follows was used for embankment construction.

The tire shred is substantially free of loose metal fragments. Exposed metal along the cut faces of the tire chips is not considered loose metal fragments. However attached residual metal protrusions extending beyond the cut faces of tires are kept to a minimum.

The tire shred used in the embankment is reasonably clean and free from contaminates, such as oil, grease, etc., that could affect the quality of ground water. Tire remains from fires are not used.

The maximum size of tire shred is 1.5 in. Figure 3.1 shows typical tire shred material used in this project. Steel belts in tires are partially removed and the unit weight of tire shred before compaction is 4.95 kN/m^3.

3.2.2 Granular Soil

According to the Indiana Department of Transportation (INDOT) specification, B borrow fill material, #24 sand, was used as granular soil for tire shred and soil mixture. This granular soil is uniformly graded sand with less than 6% of fines that passes No. 200 sieve. Figure 3.2 shows the grain size distribution of the granular soil used. Specific gravity of sand is 2.67 and unit weight without compaction is 17.48 kN/m3. Table 3.1 shows shear strength values of sand determined by direct shear tests.

3.2.3 Tire Shred and Sand Mixture

Tire shred and sand were mixed with mixture ratio of 50/50 by volume (23/77 in weight ratio of tire shred to sand). The total volume of tire/soil material used for the embankment before compaction was 840 m^3 (420 m^3 of Tire and 420 m^3 of sand). The unit weight of tire/soil material after compaction is 11.53 kN/m^3 and volume of tire/soil embankment after compaction is 813 m^3.

Table 3.1 Shear Strength of Granular Soil

Sample No.	Relative density description	γ_d (kg/m^3)	D_R (%)	Normal stress (kN/m^2)	Peak stress (kN/m^2)	Residual stress (kN/m^2)	ϕ_p	ϕ_r
1	Loose	1646	25.3	32.4	23.7	23.4	36.84	36.11
2		1657	29.1	126.2	94.7	94.5		
3		1657	29.1	219.3	164.2	158.6		
4	Dense	1822	81.19	32.4	223.4	31.6	43.60	37.40
5		1835	84.89	126.2	870.1	110.1		
6		1822	81.19	219.3	1512.1	158.8		

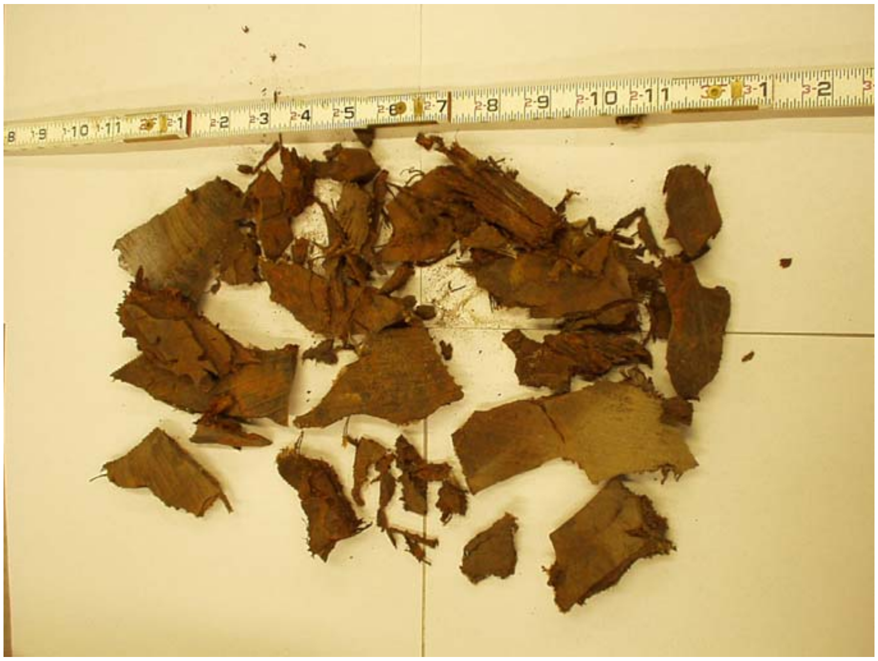

Figure 3.1 Tire Shreds Used for the Embankment

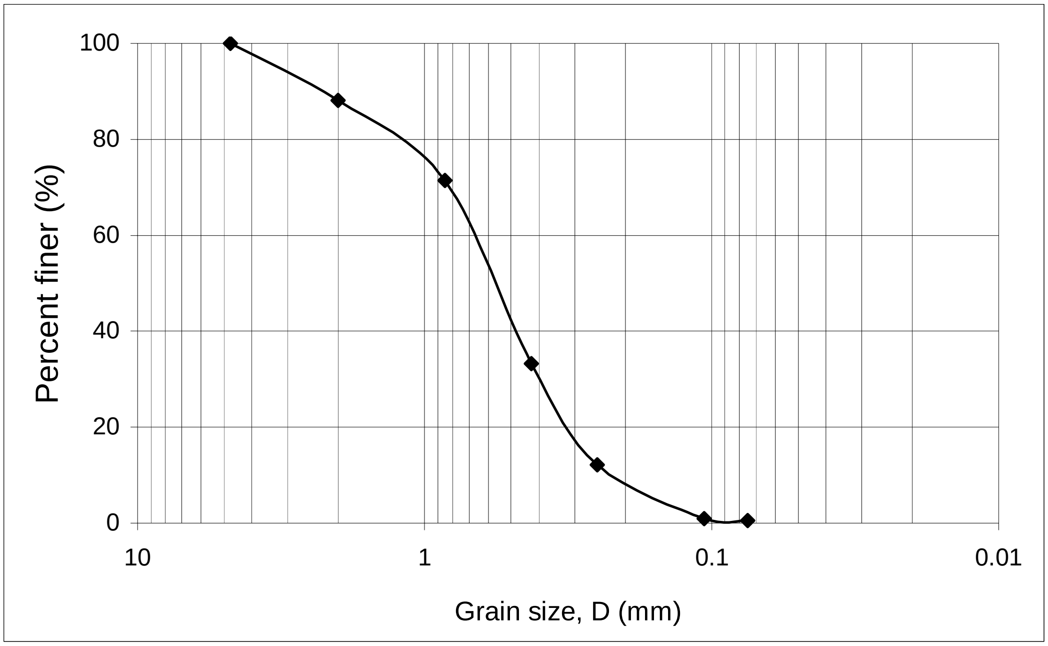

Figure 3.2 Grain Size Distribution of Granular Soil

3.3 Construction of Embankment

In July and August 2001, the tire/soil embankment was constructed for two months. The subgrade was prepared and a 150 mm (6in) thick layer of compacted aggregate base was placed and compacted. A layer of geotextile was laid on the compacted aggregate base as shown in Figure 3.3. The geotextile was laid transversely with an overlap between rolls of 600mm. The transverse splices of the geotextile were pinned with hog ring clips. Figure 3.4 and Figure 3.5 show a detailed layout of the geotextile layer.

A 300mm (1ft) thick lift of premixed tire shred and soil mixture was placed on the filter fabric. Each layer of tire shred and soil fill was uniformly placed across the full width of the roadway cross section. Compaction of the tire and granular fill mix was conducted with a D6 10 ton bulldozer with vibrating steel drum roller. To achieve proper compaction, the minimum number of passes was 6 times. A rubber tire roller (Caterpillar) was used to spread out the fill material as secondary compaction.

As shown in Figure 3.3, the tire and soil embankment was covered with 0.9 m (3 ft) of cohesive encasement material. The encasement material was placed and compacted at the same time the tire and soil lift was placed. Seeding of the encasement material was performed. Figure 3.6 shows a schematic diagram of the cohesive material encasement of the tire and soil embankment.

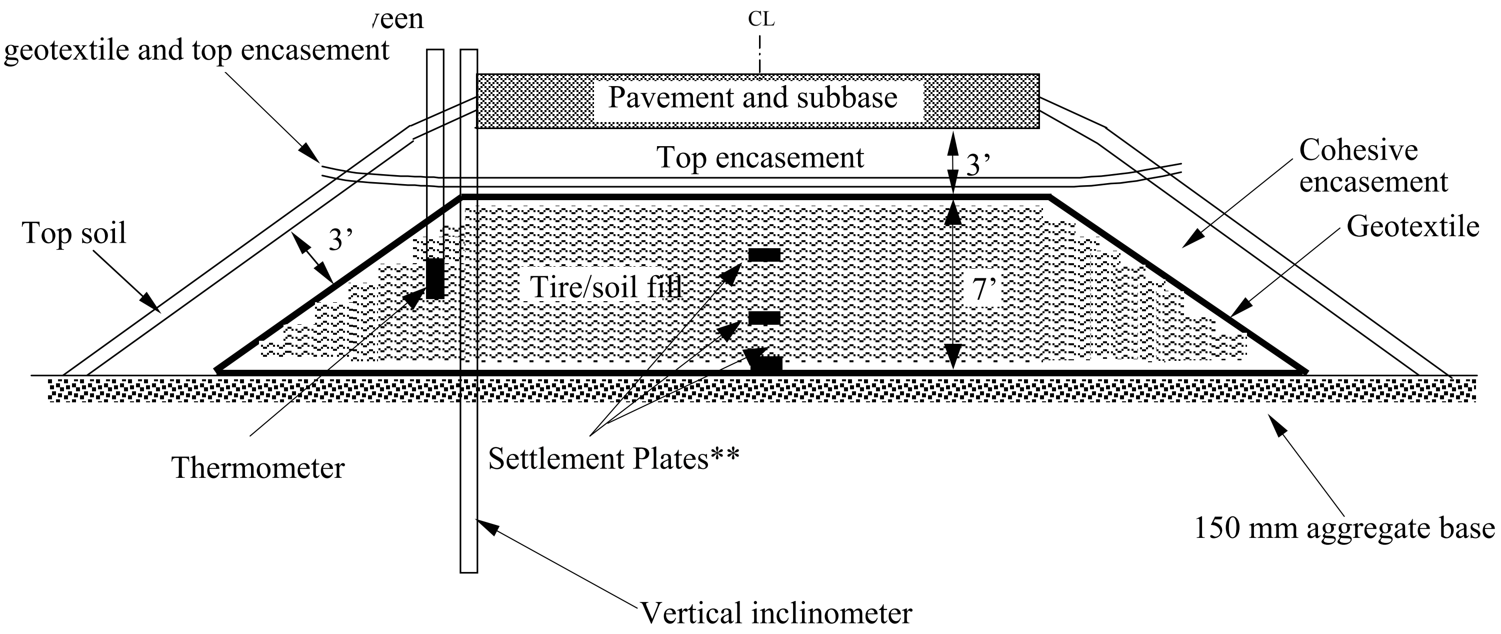

Figure 3.3 Schematic Diagram of Tire Shred and Soil Embankment

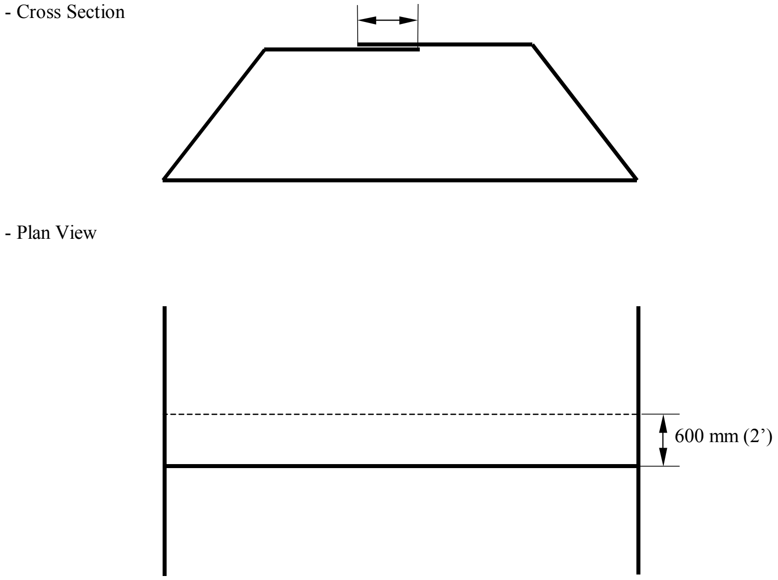

Figure 3.4 Layout of Non-woven Geotextile

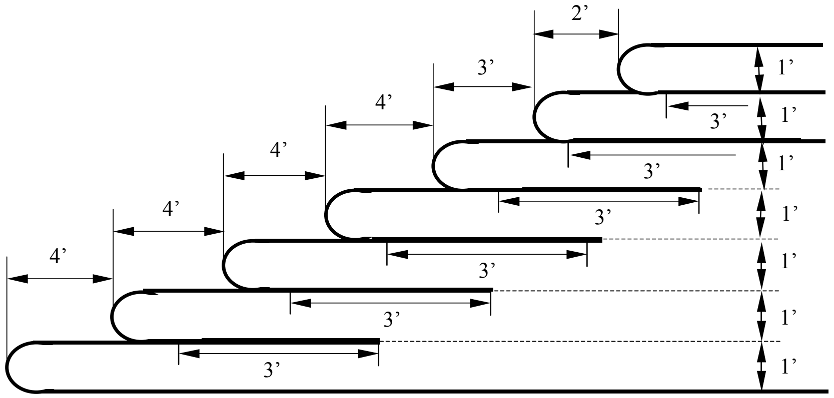

Figure 3.5 Geotextile Details of Side Slope

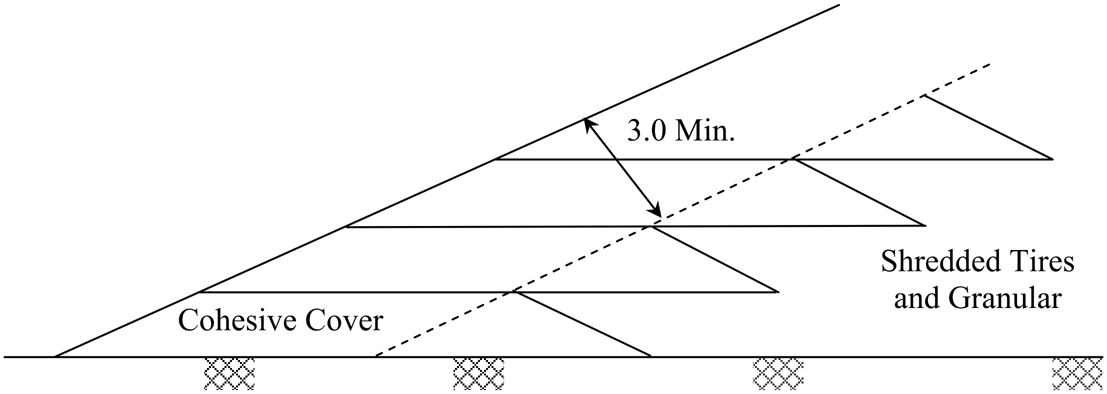

Figure 3.6 Cohesive Material Encasement of Side Slope

CHAPTER 4. FIELD TEST AND INSTRUMENTATION

4.1 Settlement Plates

Nine settlement plates were installed at three different depths in three different sections (Northeast, Center and Southwest sections) as shown in Figure 4.1. Field monitoring was conducted for a year after the road was opened to traffic. The tire/soil fill is compressed due to the embankment weight itself and traffic. The results from field monitoring are plotted in Figure 4.2 through Figure 4.4.

As shown in the plots, the settlement of the tire/soil embankment is very small. The settlement after opening the road for traffic was approximately 12 mm. The foundation soil shows very small settlement. These results show the settlement stabilized after about 200 days of continuing traffic.

Observations took place over a year. The tire/soil embankment appeared to perform well and did not show any signs of settlement, lateral movement or erosion. No cracks on the road or ground surface movements were observed. The embankment slopes retained their original form. The instrumentation results confirm that the embankment of this project performed well.

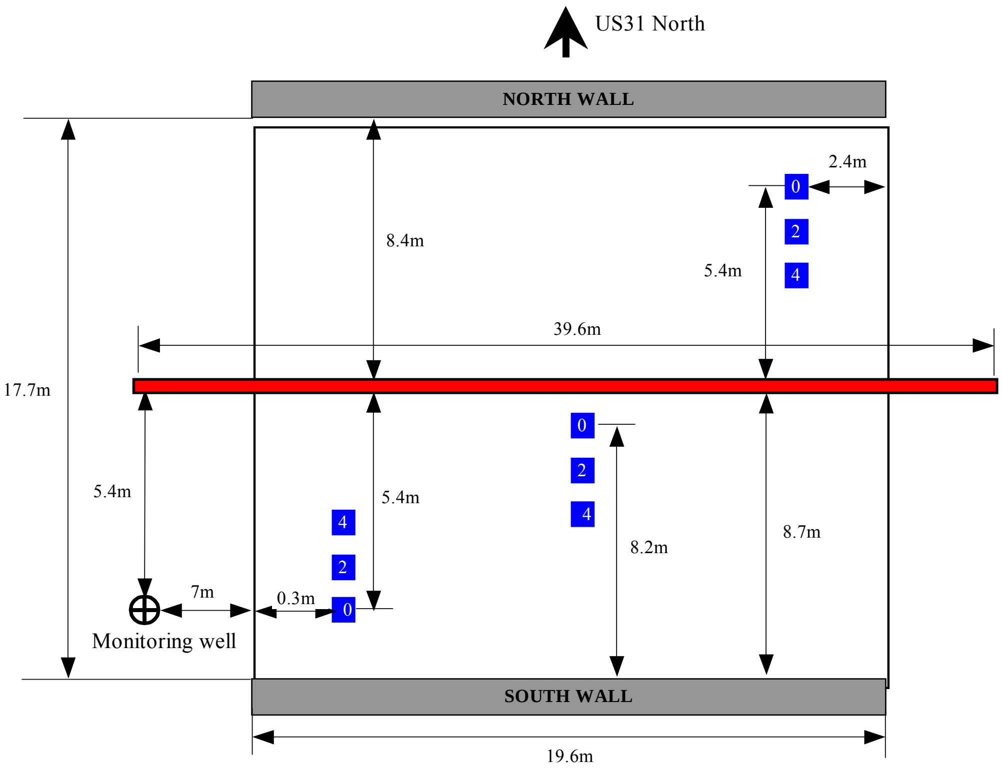

Figure 4.1 Layout of Settlement Plates

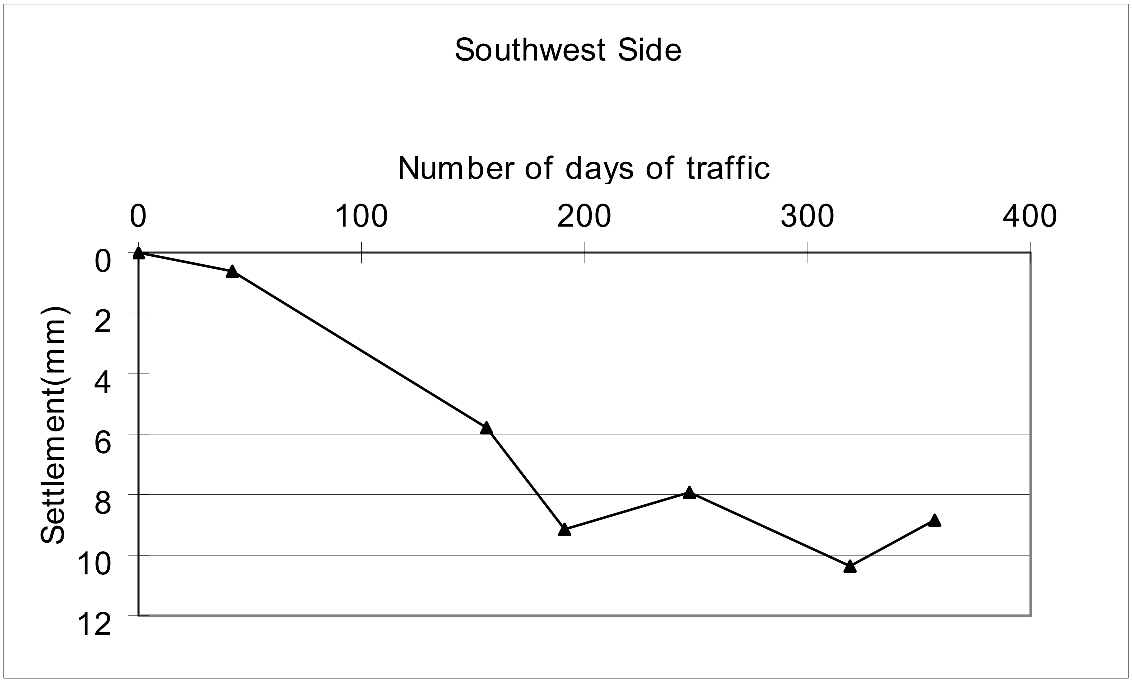

Figure 4.2 Maximum Settlement on Southwest Side

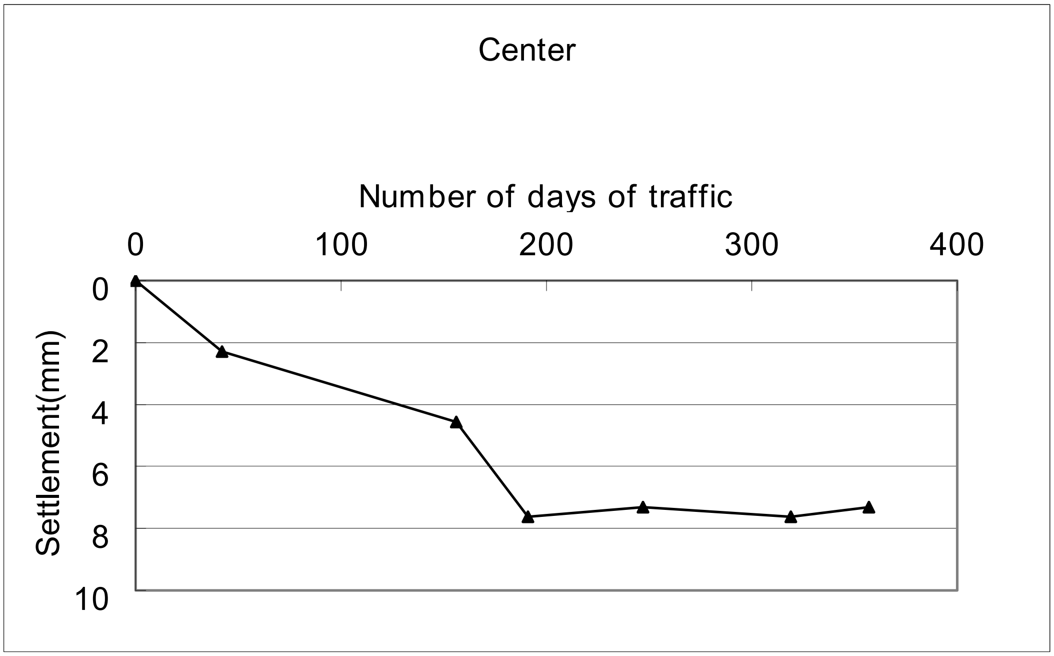

Figure 4.3 Maximum Settlement at the Center

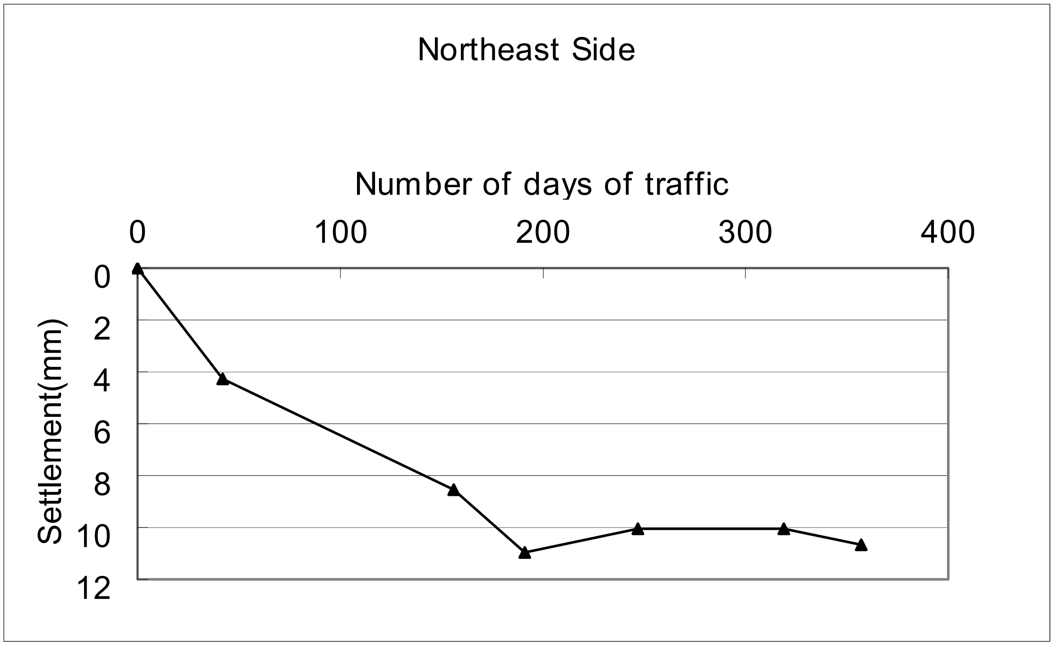

Figure 4.4 Maximum Settlement on Northeast Side

4.2 Vertical Inclinometer

As shown in Figure 3.3, a vertical inclinometer casing was installed on the east side of the embankment, near the horizontal slope inclinometer, to monitor the lateral movement of the tire/soil embankment. The schematic diagram of the vertical inclinometer casing is shown in Figure 4.5. A hole with a diameter greater than that of the vertical inclinometer casing was drilled. After that, the vertical inclinometer casing was installed. The gap between the casing and the soil was filled with cement slurry. Lateral movement was monitored using the vertical inclinometer for a year after opening road for traffic. Figure 4.6 shows the results of vertical inclinometer monitoring. Lateral movement took place over 50 days and maximum vertical movement is approximately 5 mm, which is a small value. No evidence of slope stability problem was observed.

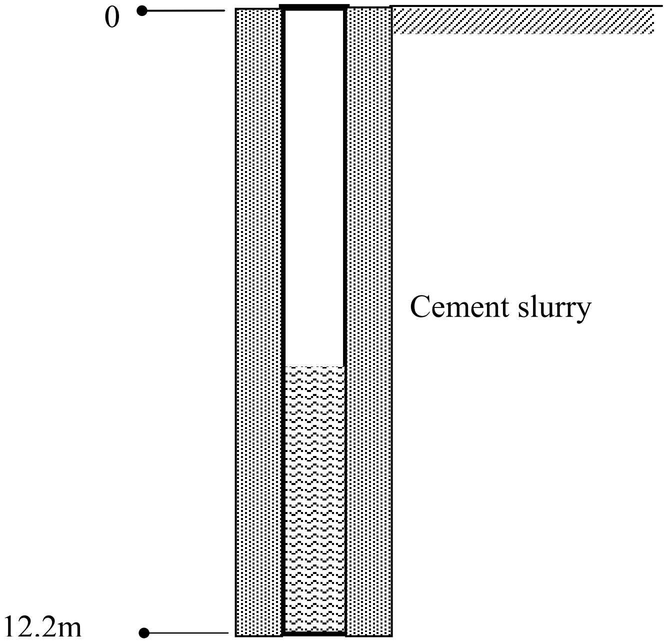

Figure 4.5 Casing for Vertical Inclinometer

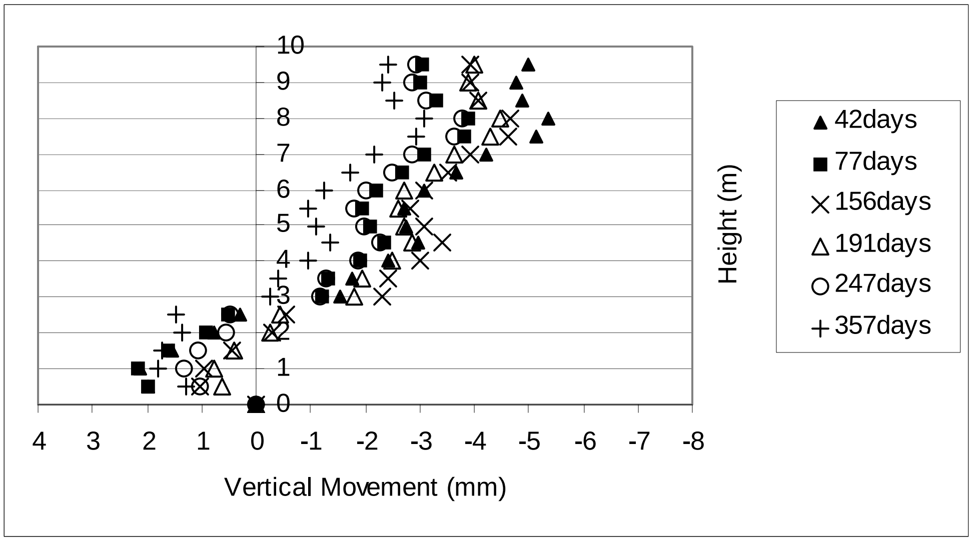

Figure 4.6 Lateral Movement of Embankment

4.3 Horizontal Inclinometer

As shown in Figure 3.3 the horizontal inclinometer casing was installed between the geotextile and top encasement to monitor differential settlement within the embankment Monitoring using the horizontal inclinometer was conducted 77 days, 191days and 247 days after opening the road to traffic. The horizontal inclinometer results are shown in Figure 4.7. The calculated maximum settlement is approximately 11 mm. This matches well with the results from settlement plate monitoring. The results do not show significant differential settlement through the embankment.

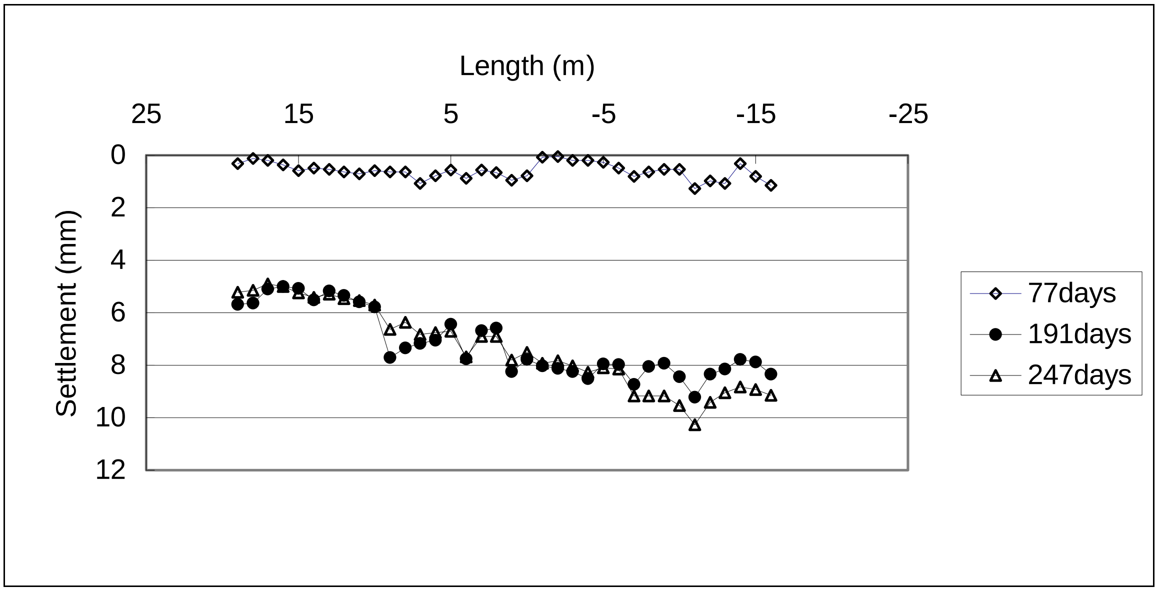

Figure 4.7 Horizontal Inclinometer Measurements

4.4 Groundwater Monitoring Well

To check the effect of the tire/soil embankment on water quality, a monitoring well was installed on the southwest side of embankment, to a depth of 45 feet as shown Figure 3.3. The schematic diagram of the monitoring well is shown in Figure 4.8. During well installation, the groundwater was observed at 37 feet deep. The bentonite grout prevents surface water or rain fall from penetrating into ground water through the collection area in the screen casing. The bentonite chips expand with moisture and fixes the casing. For sand fill, No.4 sand was used. It serves as drainage layer and allows ground water to enter into the screen casing.

The groundwater was monitored after road opening for traffic. Table 4.1 indicates the results of water quality analyses performed on several samples taken from monitoring well. Samples have been tested basically for metals. This analysis was done to check against the secondary drinking water standard and standard of maximum contaminant level for drinking water from Indiana Department of Environmental Management (IDEM).

Results from water quality analysis show that all metals except manganese are well below the secondary and maximum contaminant level for drinking water IDEM standard level. But manganese is not a health concern. The exposed steel belts containing 2-3 percent manganese by weight is thought to be the source of the manganese (Humphrey et al. 2000).

Table 4.1 Groundwater Quality Analysis

Contaminant	Unit	Secondary drinking water	9/05/2001	10/17/2001	11/21/2001
Aluminum	mg/L	0.05 to 0.2	0.0478	0.1891	0.1171
Iron	mg/L	0.3	0.0342	0.0928	0.0734
Manganese	mg/L	0.05	0.0696	0.0826	0.1649
Zinc	mg/L	5	0	0.0175	0.023
Contaminant	Unit	Maximum contaminant level for drinking water (IDEM)	9/05/2001	10/17/2001	11/21/2001
Arsenic	mg/L	0.05	0.0166	0.0148	0.0186
Barium	mg/L	2	0.0943	0.0962	0.1132
Cadmium	mg/L	0.005	0.00075	0.0011	0.0003
Chromium	mg/L	0.1	0.03625	0.05513	0.04965
Selenium	mg/L	0.05	0	0.01753	0.023

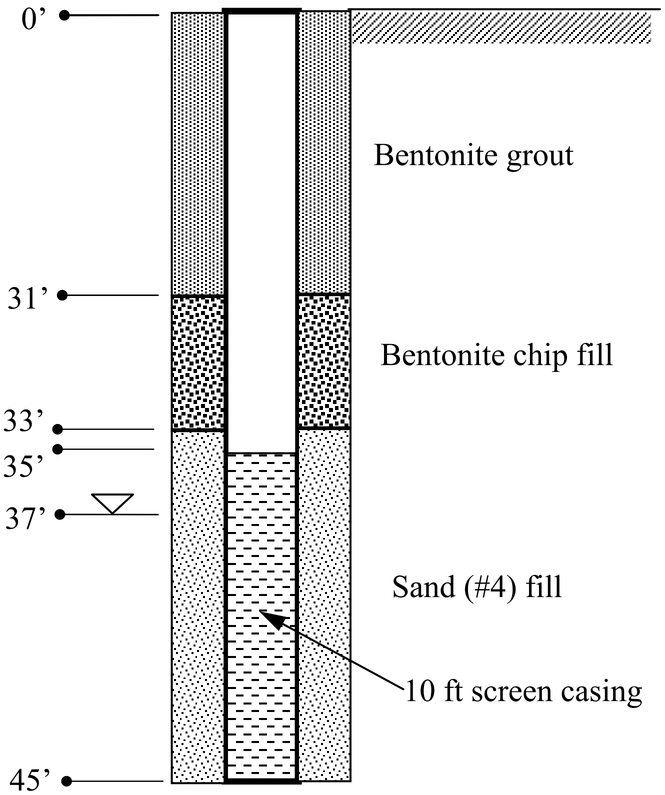

Figure 4.8 Schematic Diagram of Groundwater Monitoring Well

4.5 Thermometer for Exothermic Reaction

Exothermic reaction has been a very critical issue in tire shred embankment project since the projects in Washington and Colorado that experienced self-heating inside of the embankment. However, there is significant difference between this embankment and the embankments that heated up. The fill material in this project is 50/50 tire/soil mix in volume. Temperature inside the embankment has been monitored for a year. Figure 4.9 shows temperature monitoring results for the embankment. No evidence of exothermic reactions has been detected. This result confirms the idea that a tire shred and soil mixture is a promising material to prevent inner exothermic reaction.

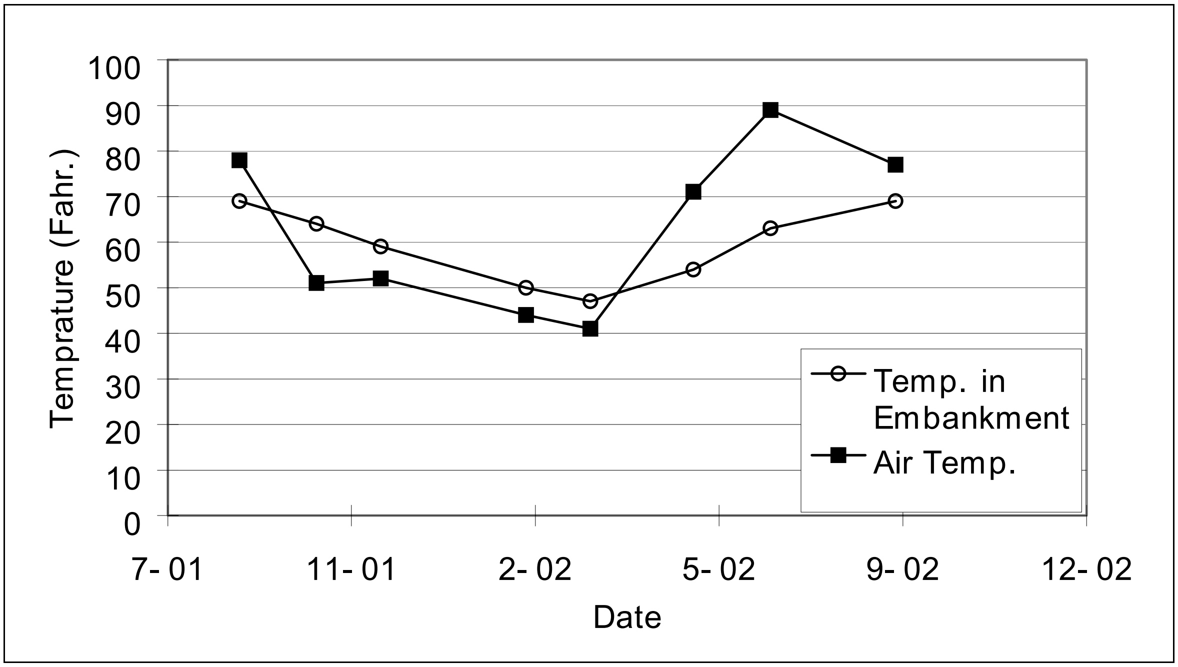

Figure 4.9 Variation of Temperature with Time

CHAPTER 5. OPTIMUM SIZE OF TIRE SHREDS AND OPTIMUM MIXING RATIO OF TIRE SHREDS AND SAND

5.1 Optimum Size of Tire Shreds

Tire shred sizes are usually in the 50 mm (2 in) to 300 mm (12 in) range. Whole tires or parts of scrap tires are shredded by shredders equipped with knives or blades. A typical tire shredding operation is performed as follows:

1) the tires are brought into the facility;
2) the tires are carefully inspected for any foreign debris; tire tubes and liners are also removed and recycled;
3) the tires are loaded onto the conveyor feeding system;
4) the tires pass through numerous shredders and are reduced in size to 12 inches or less depending on the setup;
5) after completing the shredding process, the tire shreds travel through a trammel; oversized rubber pieces are recirculated through the shredder until those pieces can pass through the sizing trommel.

Usually, multiple passes through the shredder are required for tire shred sizes of less than 300mm (12 in) (GeoSyntec Consultants, 1998).

Shredded tires are often graded by mesh size. Mesh size is the number of pieces per square inch. Table 5.1 shows the price for each size of shredded rubber according to the California Integrated Waste Management Board (2001). The table shows that it is more costly to produce and more expensive to obtain a smaller size of tire shred. From a cost effectiveness viewpoint, larger-size tire shreds are more desirable as construction materials, but the engineering properties of tire shreds must also be considered.

Ahmed (1993) conducted triaxial tests with two different sizes of tire shred (0.5 in and 1 in). According to his test results, the size of the tire shreds does not significantly affect their shear behavior. However, according to Bosscher (1992), it is desirable to use smaller size tire shreds of 50 mm (2 in) or less to avoid potential problems with compaction.

Table 5.1 Price of Shredded Rubber

(California Integrated Wasted Management Board, 2001)

Mesh Size	FOB Price per Pound
10 Mesh	10-18 cents
40 Mesh	14-22 cents
80 Mesh	25-52 cents

5.2 Optimum Mixing Ratio of Tire Shreds and Granular Material

Tire shreds have been used either separately or mixed with soil. Mixing of tire shreds and soil improves the compactibility of the fill. The unit weight of the mixture of tire shreds and soil increases as the soil content increases. Ahmed (1993) conducted triaxial tests with various mixing ratios of tire shred (0.5 in and 1 in) and granular soil. The tire shred/mix ratio varied from 0% to 67% by weight. The maximum deviatoric stress of the mixtures of tire shreds and sand increases as the ratios of tire shreds to sand increase up to 40% for low and medium levels of confining pressures. A tire shred/soil ratio of about 40% was proposed as an optimum ratio for tire shred and sand mixtures based on triaxial test results.

One of the principal advantages of mixing tire shreds and soil is to reduce the combustibility of tire shred fills. As addressed in section 2.5, the occurrence of an exothermic reaction involving the shreds has been a very critical issue in tire shred embankment projects. The presence of sufficient air in the tire shred fill may have played a role in the ignition process (Humphrey, 1996). To prevent self-ignition, isolation of the tire shred is required. When tire shreds are, on average, floating in a soil matrix, isolation of the tire shreds is practically ensured.

Lade (1998) proposed a theoretical formulation for the void ratios in binary packing. Figure 5.1 shows a schematic diagram of the variation of the minimum void ratio in a binary packing of sand particles and fine particles. His findings can be used for mixtures of tire shreds and sand. On the left end of the plot of Figure 5.1 with 100% tires shreds, the tire shreds form a structure with an initial void ratio e_{tire}. When sand particles are added to the voids between the tire shreds, the sand particles fill the voids between tire shreds. The overall void ratio (e_{tot}) decreases without changing the overall volume of tire shreds and sand mixture until the voids between tire shreds are fully filled with the sand particles. If all voids between tire shreds are filled with sand particles, any further addition of sand will increase the overall void ratio (e_{tot}) as well as the overall volume as shown in Figure 5.1 and Figure 5.3. Thus the minimum overall void ratio (e_{tot}) is reached when the voids in the tire shreds are completely filled with sand particles. From that point, on further addition of sand, mixtures are obtained in which the tire shreds are on average floating in a sand matrix.

Ahmed (1993) performed vibration compaction tests on the mixture of 1-inch tire shreds and Ottawa sand with various mixing ratios. The laboratory testing was conducted to find the variation of the dry density with different mixing ratio of tire shreds and sand. Using a vibratory table (ASTM 4253), the oven dried sand was compacted and the maximum density of the sand was determined by several trials. Then the sand was mixed with tire shreds at different mixing ratio. The mixing ratio of tire shreds was varied from 0 to 100% by dry weight (i.e. from pure sand to pure tire shreds). Table 5.2 shows the compaction results from tests on the tire shred and sand mixture. As shown in Figure 5.2, the density of the mixture of tire shreds and sand increases linearly with increasing percentage of sand, since the specific gravity (G_S) of the sand is larger then that of the tire shred. The specific gravity (G_S) of the sand and tire shred are 2.65 and 0.95 respectively.

From his test results, the total overall void ratio (e_{tot}) was calculated and plotted as shown in Figure 5.2. The pure tire shred material and pure sand material have initial void ratios of 0.92 (e_{tire}) and 0.39 (e_{sand}), respectively. As the percentage of sand increases, the overall void ratio (e_{tot}) decreases as discussed above. With 39% of tire shreds mixture by weight, the minimum overall void ratio (e_{tot}) is reached.

Base on these results, the minimum mixing ratio of the sand to tire shreds that ensures the isolation of the tire shreds is determined as 61:39 by weight (36:64 by volume).

In this project, an approximate 50/50 volumetric ratio of tire shred and soil was used so that tire shred usage is not reduced significantly.

In summary, the optimum mixing ratio can be determined experimentally, since the shape and size of the tire shreds vary significantly depending on the shredding method and equipment settings. For similar projects where the mixtures of tire shreds and granular material are used as fill material, the following procedure can be used to determine an optimum mixing ratio:

1) determine the size of tire shreds and shredding method;
2) perform vibration compaction tests on the mixture of tire shreds and soil with various mixing ratios;
3) using the values of specific gravity of the tire shreds and soil particles, calculate the overall void ratio of the tire shreds and soil mixture;
4) the mixing ratio producing a minimum overall void ratio is the minimum mixing ratio that ensures an floating of the tire shreds in a soil matrix.

Table 5.2 Vibration Compaction Results from Tests on 1 inch Tire Shreds and Ottawa Sand Mixture

(after Ahmed, 1993)

Tire shreds (%)	Dry density (pcf)
0.00	118.75
4.76	115.02
9.09	110.04
13.04	106.65
15.48	104.79
16.50	102.58
16.67	101.76
16.70	103.82
20.00	99.27
23.08	96.95
23.10	99.34
25.93	93.15
29.16	94.86
30.07	95.53
31.30	91.66
37.00	86.09
37.72	88.08
38.78	88.28
39.32	89.25
39.37	88.94
40.00	84.75
44.00	73.13
49.66	66.70
50.00	72.70
66.54	54.72
100.00	30.95

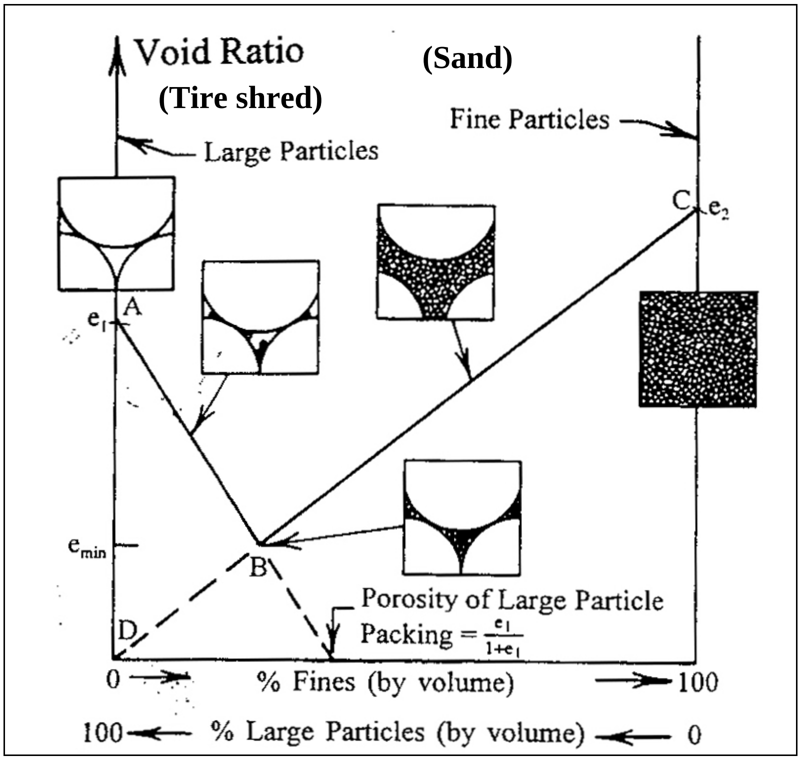

Figure 5.1 Schematic Diagram of Theoretical Variation of Minimum Void Ratio in Binary Packing (after Lade, 1998)

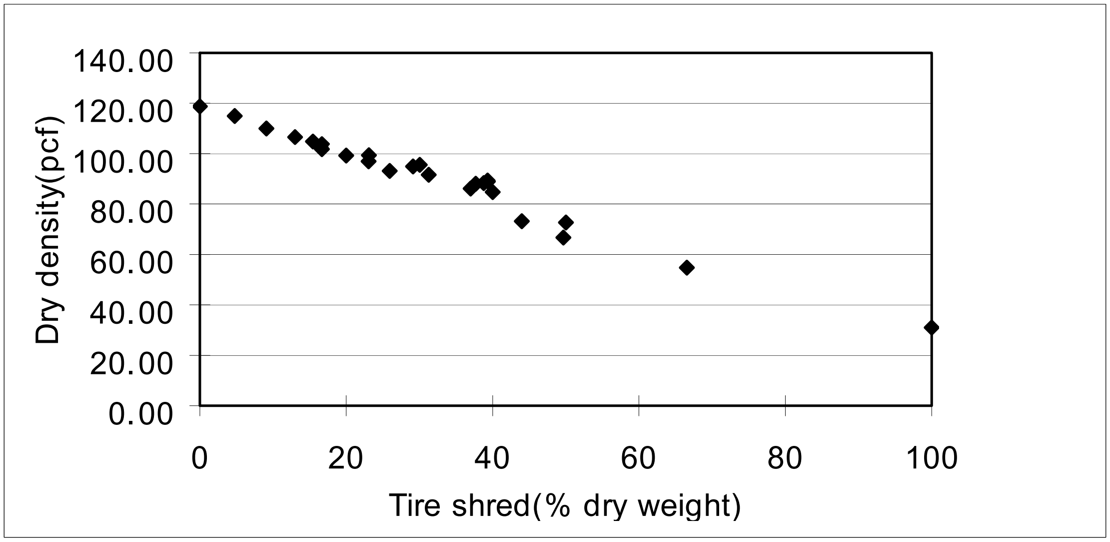

Figure 5.2 Vibration Compaction Test on Tire Shred and Sand Mixture with Various Mixing Ratio

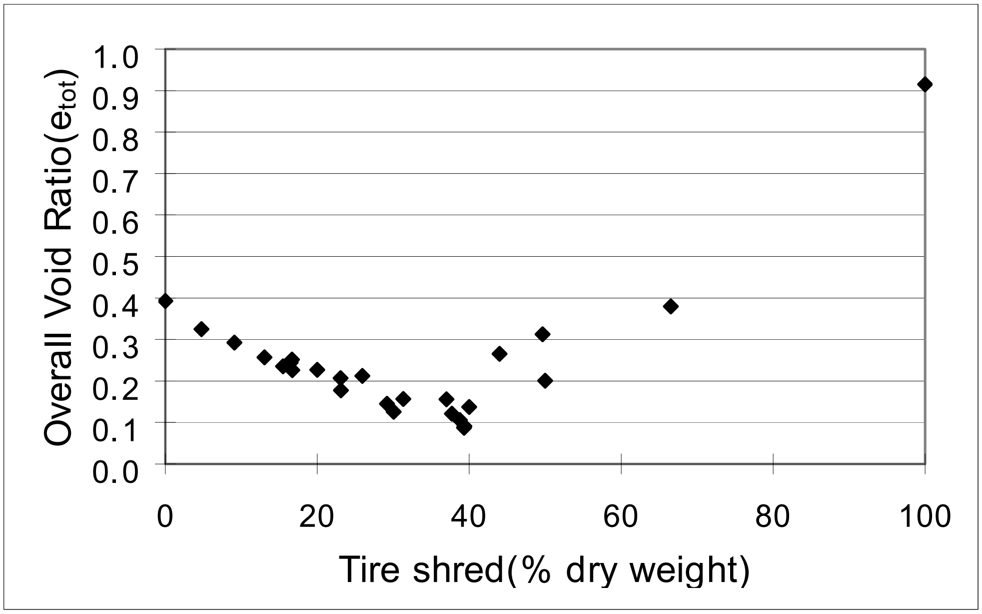

Figure 5.3 Overall Void Ratios of Tire Shred and Sand with Various Mixing Ratios

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the investigation and monitoring of the tire shred and soil embankment test site, the following observations and conclusions are proposed:

(1) At State Rd. 31 in Lakeville, IN. a tire shred and soil embankment was constructed. The fill material was a 50/50 mixture by volume of tire shred and soil. The total volume of the embankment after compaction was approximately 813 m^3. The height and length of the embankment were about 2 m and 20 m respectively.

(2) Monitoring using nine settlement plates at three different sections was conducted for a year after opening the road for traffic. The maximum settlement was approximately 12 mm and the settlement stabilized after 200 days of traffic.

(3) Vertical and horizontal inclinometer monitoring was conducted to check lateral movement and differential settlement for one year. Maximum lateral movement was about 5 mm. No evidence of significant differential settlement has been observed.

(4) Samples of groundwater were analyzed for metals which apply to a secondary drinking water standard and standard of maximum contaminant level for drinking water according to Indiana Department of Environmental Management (IDEM). Except for manganese, all levels have been well below the standard limits. However manganese is not a health concern.

(5) To check for the possible development of exothermic reactions that might lead to the initiation of fires in the embankment, the temperature was observed for a year.

No evidence of internal heat generation has been detected. This confirms that the use of tire shred and soil mix is a proper way to prevent self-heating of the tire shreds.

(6) Observations show no signs of slope stability problems, cracking on the road or erosion.

6.2 Recommendations

(1) Based on the above findings and observations, using a mix of tire shreds and soil in embankments or fills is very promising and should be promoted. Performance of the test embankment was quite satisfactory. Advantages of this material include the fact that it is lightweight, relatively cheap, easy to compact, free-draining and relatively compressible. Additionally, this use is beneficial to the environment in that a waste material is recycled.

(2) Given the characteristics of soil-tire shreds mixer, these mixer can be used as backfill material for retaining structures. Since tire shreds are lightweight, they induce low horizontal stresses thus reducing the thickness of retaining structures. Similar cost savings will be possible for MSE walls as well.

(3) Based on the experience of the construction of the test embankment in this project, a special provision for the embankment constructed of shredded tires and granular fill is provided in Appendix A.

(4) To prevent self-ignition, floating of the tire shred in a soil matrix is desired. The minimum mixing ratio that produces such an arrangement can be determined by vibration compaction tests. The mixing ratio producing a minimum overall void ratio is the minimum mixing ratio leading to this arrangement. Other mixing ratio can be explored in order to increase the strength of other result mixture.

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APPENDIX A. Special Provision

EMBANKMENT CONSTRUCTION USING TIRE SHREDS-GRANULAR (TSG) MIX

DESCRIPTION:

This work shall consist of using tire shreds-granular (TSG) mix for constructing embankment in accordance with 105.03. Adherence to the provisions herein does not preclude applicability of local, state or federal regulations, and laws.

MATERIALS: Tires may be chipped or shreds and is defined as tire shreds. Tire shreds shall be restricted to Indiana Department of Environmental Management (IDEM) wastes classifications of type IV and type III as defined by 329 IAC 2-9-3.

Tire shreds shall comply with the following:

- All the pieces must have at least one sidewall severed from the face of the tires. The largest allowable piece shall be 12 inches or less in length.
- 80% of the shredded or chipped tires (by weight) must pass an 8 inch screen.
- A minimum of 50% of the material (by weight) must pass a 4 inch screen.
- The tire shreds shall be substantially free of loose metal fragments. Exposed metal along the cut faces of the tire

shreds will not be considered loose metal fragments. However, attached residual metal protrusions (beads and belts) extending beyond the cut faces of tires shall be kept to a minimum.

- Tire Shreds and granular mix shall be 60:40 by volume respectively.

SITING CRITERIA: TSG Mix shall not be placed in the following cases:

- Below the seasonal high water table.
- Within 100 horizontal feet of a perennial stream/river and lake/reservoir.
- Within 150 horizontal feet of a well, spring, or other ground water source of potable water.
- Adjacent to a wetland or other protected environmental resource area.
- TSG Mix shall not be used directly under pavement. TSG Mix embankment shall be covered with 3 feet of encasement material.

LIMITATIONS:

- TSG mix shall be used as fill up to 10 ft. high.
- Settlement plates shall be installed at the bottom and top of the TSG mix and placed at 50 feet apart.
- Settlement shall meet the requirements of Section 204 prior to the placement of the pavement.

STORAGE:

Tire shreds may be stored with the R/W of the project with the approval of the Engineer. They shall not be placed adjacent to commercial or residential areas. Stockpiling shall be considered a temporary measure to assist in construction activities and material contained therein shall be incorporated into the fill within 14 calendar days of the inception of the stockpile. The stockpiled volume shall not exceed cubic yards.

CONSTRUCTION REQUIREMENTS:

Subgrade shall be prepared in accordance with 201 and a layer of geotextile shall be laid subgrade. The geotextile shall be laid transversely with an overlap between rolls of 18 in. End to end splices in the geotextile will not be permitted. The transverse splices of the geotextile shall be pinned with hog ring clips.

A 12 in. thick lift of TSG mix shall be placed on the Geotextile. A layer of the TSG mix shall result in a substantially uniform distribution of materials. A TSG mix lift shall be placed full width of the roadway cross section. Compaction of TSG mix shall be performed with a smooth vibratory compactor in accordance with 408.03(d) and weighing 10 tons. It is expected that 6 to 8 passes shall be required to achieve in each lift, proper compaction. However, the number of passes may increase if the deformation in each lift is more than 1/4 in. The top 3 ft. of embankment shall be constructed with soil, in accordance with Section 207.02.

The TSG mix shall be covered with 3 feet of cohesive encasement material. The encasement material shall be placed and compacted at the same time as the TSG lift is placed. Seeding of the encasement material shall be in accordance with 621.

METHOD OF MEASUREMENT:

Fill materials (Granular Fill, Tire Shreds, and Cohesive Soil) will be measured by the cubic yard based on plans. Geotextile will be measured in accordance with 616.11. Settlement plates will be measured in accordance with 204.04 Encasement (sides and top) materials will be measured by the cubic yard based on the theoretical volume.

BASIS OF PAYMENT:

The accepted quantity of TSG is the contract unit price per cubic yard. Geotextile will be paid for in accordance with 616.12. Settlement plates will be paid for in accordance with 204.05. The accepted quantities of encasement (sides and top) materials will be paid for at the contract unit price per cubic yard, complete in place.

Payment will be made under:

Pay Item	**Pay Unit Symbol**
Encasement Material	(CYS)
Tire Shreds Granular (TSG) mix	(CYS)

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