CONSTRUCTION OF MSE WALL USING TIRE SHRED-SAND MIXTURE AS BACKFILL

SPR-3470

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Final Project Report (PPT)

Construction of MSE Wall using Tire Shred-Sand Mixture as Backfill

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SPR - 3470

Purdue University, West Lafayette

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- ▣ Project Overview
- ▣ Construction of the MSE wall using tire shred-sand mixtures
- ▣ Tasks
- ▣ Design Summary

Background

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- ▣ Existing pavement at I-80 needed widening
- ▣ A tire shred-sand mixture and EPS were used as backfill for MSE wall No. 54
- ▣ The tire shred-sand mixture was designed to be lightweight to minimize vertical settlement of the MSE wall
- ▣ The geotechnical properties needed for design were determined
- ▣ The performance of the wall was monitored

Project Overview

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I-80/94 interchange modification (Wall No. 54)

- ❑ Lake County, Indiana
- ❑ Sta. 676+00 "M" to Sta. 681+00 "L"
- ❑ Wall height = 10 ft
- ❑ Backfill: tire shred-sand mixture + EPS
- ❑ Mixing ratio by volume (loose state):
 - ❑ 60 (tire shred):40 (sand)
- ❑ Materials used (compacted state):
 - ❑ Shredded tires: 2,000 yd³
 - ❑ Sand: 1,300 yd³
- ❑ No. of compactor passes = 4~5

Construction of MSE wall

MIXING PROCESS

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Construction of MSE wall

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Installation of leveling pad

Facing panels ready to be installed

Placement of MSE Wall facing panels

Construction of MSE wall

BACKFILLING

8

Aggregates on the bottom of the fill

Hauling and spreading the mixture

Compaction of the mixture
(10-ton roller, lifts of 12 inches)

Construction of MSE wall

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Connection of reinforcement to facing

Installation of EPS blocks

Installed reinforcements

Aggregate and reinforcing bars on the EPS

Tasks

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Tasks in the proposal

- ❑ Assess compaction characteristics of mixture
- ❑ Supervise MSE wall construction
- ❑ Perform QC tests during construction
- ❑ Assess performance of wall
- ❑ Prepare a power point presentation with results

Additional Tasks

- ❑ Perform lab tests at 3 different mixing ratios – 50:50, 60:40 and 70:30 by volume of TS : Sand
 - Laboratory pullout tests
 - Direct shear tests
- ❑ Include design summary in the ppt

Tasks – Field Monitoring

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Tasks – Field Monitoring

RESULTS

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- ▣ *Vertical movement:* Negligible movement (about 3 mm) was observed after construction
- ▣ *Crack gauges:* Reading of less than 1 mm was measured
- ▣ No significant compression of the mixture, was measured
- ▣ No additional deformation of the wall was observed

Tasks

LABORATORY PULLOUT TESTS

Tasks – Laboratory Pullout Tests

EQUIPMENT AT PURDUE UNIVERSITY, WEST LAFAYETTE

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- Box dimensions: 1.0 x 0.38 x 0.47 m
- Shear rate: 1 mm/min

Tasks – Laboratory Pullout Tests

SAMPLE

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2~4 inches
(50-100 mm)

Mixed in buckets

Tasks – Laboratory Pullout Tests

REINFORCEMENT

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'Reinforcement Ladder' (Metal strap)

Tasks – Laboratory Pullout Tests

SCHEMATIC OF TEST

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Airbag used to apply confining pressure on sample
40, 65 and 90 kPa were the pressures used

Tasks – Laboratory Pullout Tests

SAMPLE PREPARATION

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- Operating pressure: 551 kPa
- 4500 vibrations/min
- 4 layers
- 5 minutes/layer

Pneumatic piston-type compactor

Tasks – Laboratory Pullout Tests

TEST RESULTS – 0:100, 50:50 Mixing Ratios by Volume

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Tasks – Laboratory Pullout Tests

TEST RESULTS – 60:40, 70:30 Mixing Ratios by Volume

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Tasks – Laboratory Pullout Tests

TEST RESULTS - POINTS TO NOTE

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Pullout capacity criteria:

In case of the existence of a peak load within 20 mm frontal displacement, it is taken as the pullout capacity. If there is no peak, the pullout load at 20 mm displacement is considered to be the pullout capacity (FHWA 2009).

Pullout resistance factor, F^* :

$$P_{ult} = F^* \cdot \alpha \cdot \sigma'_v \cdot L_e \cdot B \cdot C$$

P_{ult} = the pullout capacity of the reinforcement (peak load in case of existence of peak, else critical state load at test end – criteria 1)

F^* = the pullout resistance factor

α = correction factor to account for nonlinear shear stress distribution along the embedded length of the reinforcement (1.0 for inextensible reinforcement - Elias et. al 2001)

σ'_v = the vertical effective stress at the reinforcement-soil interface

L_e = the embedment length of the reinforcement in the resisting zone

B = the width of the metal strip (width of transverse bar = 10 cm)

C = the effective unit perimeter of the reinforcement (2.0 for strip/grid type reinforcement - Elias et.al 2001)

Tasks – Laboratory Pullout Tests

TEST RESULTS – Pullout Capacity vs. Confining Pressure

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Tasks – Laboratory Pullout Tests

TEST RESULTS – Pullout Capacity vs. Tire Shred Content

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Tasks – Laboratory Pullout Tests

TEST RESULTS – Confining Pressure vs. Pullout Resistance Factor, F^*

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Tasks – Laboratory Pullout Tests

TEST RESULTS – Summary of Pullout Test Program

25								
Tire shred- Sand mixing ratio (by volume)~	Tire shred- Sand ratio (by weight)	Confining pressure (kPa)	Maximum dry unit weight (kN/m ³) (Yoon 2006)	Average dry unit weight in pullout box (kN/m ³)	Average relative compaction (%)	Average sand- matrix unit weight (kN/m ³)	Reinforcement ladder (metal strap) pullout capacity (kN)	Pullout resistance factor, F*
0:100	0:100	40	18.0	17.2	95.6	17.2	4.2	1.31
		65					4.9	0.97
		90					6.6	0.95
50:50	20:80	40	17.1	15.6	91.2	16.7	6.1	1.91
		65					7.2	1.43
		90					8.3	1.20
60:40	25:75	40	16.6	14.8	89.1	15.8	5.5	1.73
		65					8.0	1.59
		90					9.5	1.38
70:30	35:65	40	14.2	12.3	86.5	12.3	6.4	2.04
		65					9.4	1.88
		90					9.7	1.42

Tasks – Laboratory Pullout Tests

PRACTICAL USE OF PULLOUT TEST RESULTS: 50-100 mm TS + Ottawa Sand

26		
TS : sand mixing ratio (by weight)	Equation fitted between depth (z) and F*	Coefficient of determination, R ²
20:80	$= -(z - 9.9995)/3.957$ for $0 \leq z < 7.7$ m $= \tan(\phi)$ for $z \geq 7.7$ m	0.957
25:75	$= -(z - 17.457)/8.512$ for $0 \leq z < 12.32$ m $= \tan(\phi)$ for $z \geq 12.32$ m	0.987
35:65	$= -(z - 14.108)/5.244$ for $0 \leq z < 12.32$ m $= \tan(\phi)$ for $z \geq 10.83$ m	0.922

Tasks – Laboratory Pullout Tests

SEGREGATION OF THE MIXTURE

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Segregation was assessed by removing the sample from the pullout box in layers and measuring the weights of TS and sand

- 50:50 and 60:40 ratios by weight of TS to sand showed practically no segregation
- 70:30 by weight of TS to sand showed very mild segregation, which could have been due to method of measurement of segregation
- 80:20 by weight of TS to sand showed considerable amount of segregation and hence results for this ratio were not presented

Tasks

DIRECT SHEAR TESTS

Tasks – Direct Shear Tests

SMALL-SCALE DIRECT SHEAR TEST (results not good)

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Shear machine at INDOT Research Division, West Lafayette

- Dimensions: 30 cm x 30 cm x (10 + 10) cm
- Shear rate: 1 mm/min
- The small-scale tests yielded very high friction angles, in comparison to a large-scale test performed in previous research
- As a result, large-scale direct shear tests were planned

Tasks – Direct Shear Tests

LARGE-SCALE DIRECT SHEAR TEST

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Large direct shear machine at Purdue University, West Lafayette

- Dimensions: Lower box - 1.2 m x 1 m x 0.47 m
Upper box - 1 m x 1 m x 0.5 m
- Shear rate: 1 mm/min

Tasks – Direct Shear Tests

LARGE-SCALE DIRECT SHEAR TEST

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Tasks – Direct Shear Tests

LARGE-SCALE DIRECT SHEAR TEST - RESULTS

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Tasks – Direct Shear Tests

LARGE-SCALE DIRECT SHEAR TEST - RESULTS

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Tasks – Direct Shear Tests

LARGE-SCALE DIRECT SHEAR TEST - RESULTS

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Size of tire shreds	Tire shred-Sand ratio (by volume)	Tire shred-Sand ratio (by weight)	Confining pressure range (kPa)	Critical state friction angle, ϕ_c	Peak friction angle, ϕ_p	Apparent cohesion intercept from best fit line, c (kPa)	Corresponding friction angle based on best fit line, ϕ'_c
50-100 mm	50:50	25:75	46-142	30.1	31.0	17.5	28
	60:40	20:80	60-166	30.6	31.1	5.0	28
	70:30	35:65	67-172	32.0	32.0	10.3	30

Test performed by Umashankar Balunaini, 2009, Purdue University

Tasks

DESIGN SUMMARY

Tasks – Design Summary

FORMAT ADOPTED

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The following documents were used as a basis for determining the contents of the design summary:

- ***“Plan Development Guideline for Earth Retaining Systems”*** –Design Services
- Section, Division of Design –Indiana Department of Highways, March 1989
- ***“Earth Retaining Systems”*** : Chapter 68, from ***“The Indiana Design Manual 2010”***
- ***“Standard Specifications for Highway Bridges”***–AASHTO, 17th Edition, 2002
- ***“Geosynthetic Design and Construction Guidelines”*** –FHWA, April, 1998

Tasks – Design Summary

CONTENTS

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The design summary is directed towards providing the following main properties required for design of MSE walls with tire shred-sand mixtures as backfill material:

- Characteristics of tire sand and tire shreds used in preparing the mixture (Slides 37-39)
- Mixing ratio :
 1. Conversion from weight ratio to volume mixing ratio and vice versa (Slide 40)
 2. Unit weight and relative compaction of each mixing ratio (Slide 41-42)
 3. Shear strength parameters for each mixing ratio (Slide 43)
- Types of reinforcement and their pullout characteristics (Slide 44-47)

Tasks – Design Summary

BACKFILL REQUIREMENT – SAND

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Sand used for preparing the mixture:

- *Gradation Limits:*

Sieve Size	Percent Passing
4 inches	100
No. 40	0-60
No. 20	0-15

- *Plasticity Index: $PI < 6$*
- The backfill material shall be free from organic and other deleterious materials, and free of shale or other soft, poor-durability particles. It shall have a Magnesium Sulfate soundness of less than 30 percent after 4 cycles

Tasks – Design Summary

BACKFILL REQUIREMENT – SAND

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□ Electrochemical Criteria:

Criteria	Test Method
Resistivity > 300 ohm cm	AASHTO T-288
pH: 5-10	AASHTO T-289
Chlorides < 100 ppm	ASTM D4327
Sulfates < 200 ppm	ASTM D4327
Organic Content – Max. 1%	AASHTO T-267

These are criteria prescribed in the literature, for choosing backfill soils of traditional types. A different set of electrochemical specifications may need to be adopted for tire shred-sand mixtures.

Tasks – Design Summary

BACKFILL REQUIREMENT – TIRE SHREDS

40

Tire Shreds used for the mixture:

□ Size of tire shreds:

- 2~4 inches (50-100 mm) in length in all directions

Or

- Less than 4 inches (100 mm) in all directions

Tasks – Design Summary

BACKFILL REQUIREMENT – MIXTURE PROPERTIES

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Weight to Volume Conversion

Mixing Ratio by Weight	Mixing Ratio by Volume**
20:80	~ 50:50
25:75	~ 60:40
35:65	~ 70:30

** This conversion is performed considering the minimum unit weights of Ottawa sand and 2~4 inches tire shreds used in the pullout and direct shear testing described earlier.

For example, consider a weight ratio = 20:80

- Minimum unit weight of sand (unit weight in uncompacted state), $\gamma_{s,min} = 16.6 \text{ kN/m}^3$ (~106 pcf)
- Minimum unit weight of tire shreds (unit weight in uncompacted state), $\gamma_{TS,min} = 4.1 \text{ kN/m}^3$ (~26 pcf)

$$\frac{V_{TS}}{V_s} = \frac{\frac{W_{TS}}{\gamma_{TS,min}}}{\frac{W_s}{\gamma_{s,min}}} \longrightarrow \frac{V_{TS}}{V_{Total}} = \frac{\frac{W_{TS}}{\gamma_{TS,min}}}{\frac{W_s}{\gamma_{s,min}} + \frac{W_{TS}}{\gamma_{TS,min}}}$$

$$\frac{V_{TS}}{V_{Total}} = \frac{\frac{20/100}{4.1}}{\frac{80/100}{16.6} + \frac{20/100}{4.1}} = 0.5 \longrightarrow \frac{W_{TS}}{W_s} = \frac{20}{80} \equiv \frac{V_{TS}}{V_s} = \frac{50}{50}$$

Hence, a weight ratio of 20:80 converts to a volume mixing ratio of 50:50

Tasks – Design Summary

BACKFILL REQUIREMENT – MIXTURE PROPERTIES

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Mixing ratio and corresponding geotechnical properties of the mixture:

I. Unit Weight and Required RC:

* Tire shred-sand mixtures prepared with Ottawa sand ($D_{50}=0.384 \text{ mm}$) and tire shreds of size 2~4 inches *

Mixing ratio by weight	Mixing ratio by volume	Max. dry unit weight (pcf)	Required RC (%)
20:80	~50:50	108.8	95
25:75	~60:40	105.6	95
35:75	~70:30	90.3	95

Tasks – Design Summary

BACKFILL REQUIREMENT – MIXTURE PROPERTIES

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Mixing ratio and corresponding geotechnical properties of the mixture:

II. Unit Weight and Required RC:

* Tire shred-sand mixtures prepared with B-borrow soil ($D_{10}=0.24$ mm, $D_{30}=0.35$ mm, $D_{60}=0.71$ mm) from SR 110 site in Marshall County, and tire shreds of 2 inches nominal size *

Mixing ratio by weight	Mixing ratio by volume ⁺	Max. dry unit weight (pcf)*	Required RC (%)
25:75	~50:50	103	95
35:65	~60:40	96	95
45:65	~70:30	90	95

⁺ Minimum unit weight of sand (unit weight in uncompacted state), $\gamma_{s,min} = 90$ pcf

Minimum unit weight of tire shreds (unit weight in uncompacted state), $\gamma_{ts,min} = 31$ pcf

* $\rho = 113.748 - 0.3492(TS) - 0.00400(TS)^2$, where TS is the proportion of tire shreds as a percentage

Tasks – Design Summary

BACKFILL REQUIREMENT – MIXTURE PROPERTIES

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Mixing ratio and corresponding geotechnical properties of the mixture:

* Tire shred-sand mixtures prepared with Ottawa sand ($D_{50}=0.384$ mm) and tire shreds of size 2~4 inches *

Shear Strength

Mixing ratio by weight	Mixing ratio by volume	ϕ_c (degrees)	ϕ_p (degrees)	Cohesive intercept (from best fit line), c (kPa)	Corresponding ϕ from best fit line
20:80	~50:50	30.1	31.0	14.5	27.1
25:75	~60:40	30.6	31.1	17.5	28.0
35:75	~70:30	32.0	32.0	10.3	29.6

Tasks – Design Summary

REINFORCEMENTS – TYPE AND PULLOUT CHARACTERISTICS

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REINFORCEMENT LADDERS (METAL STRAPS)

Tire shred-Sand mixing ratio (by volume)~	Tire shred-Sand ratio (by weight)	Confining pressure (kPa)	Maximum dry unit weight (kN/m ³) (Yoon 2006)	Average dry unit weight in pullout box (kN/m ³)	Average relative compaction (%)	Average sand-matrix unit weight (kN/m ³)	Reinforcement ladder (metal strap) pullout capacity (kN)	Pullout resistance factor, F*
0:100	0:100	40	18.0	17.2	95.6	17.2	4.2	1.31
		65					4.9	0.97
		90					6.6	0.95
50:50	20:80	40	17.1	15.6	91.2	16.7	6.1	1.91
		65					7.2	1.43
		90					8.3	1.20
60:40	25:75	40	16.6	14.8	89.1	15.8	5.5	1.73
		65					8.0	1.59
		90					9.5	1.38
70:30	35:65	40	14.2	12.3	86.5	12.3	6.4	2.04
		65					9.4	1.88
		90					9.7	1.42

Tasks – Design Summary

REINFORCEMENTS – TYPE AND PULLOUT CHARACTERISTICS – RIBBED METAL STRIP

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Size of tire pieces	Tire shred-sand ratio (by weight)	Tire shred-sand ratio (by volume)	Confining pressure (kPa)	Maximum dry unit weight (kN/m ³) (Yoon 2006)	Average dry unit weight in pullout box	Relative compaction (%)	Ribbed metal strip pullout capacity (kN)	Pullout resistance factor, F*
Ottawa Sand	0:100	0:100	40	18.0	17.2	95.5	4.4	1.49
			65				5.2	1.08
			90				5.8	0.87
9.5 mm size chips	25:75	50:50	40	15.2	14.3	94.3	3.2	1.08
			65				4.0	0.83
			90				4.9	0.74
50-100 mm	25:75	58:42	40	16.6	14.7	88.5	3.1	1.05
			65				3.7	0.77
			90				4.4	0.66
100-200 mm	25:75	69:31	40	16.5	14.2	86.2	3.0	1.01
			65				3.4	0.71
			90				3.8	0.57

Tasks – Design Summary

REINFORCEMENTS – TYPE AND PULLOUT CHARACTERISTICS

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GEOGRIDS

Property	Unit	Machine Direction (MD) Value
True initial modulus	kN/m	1580
Tensile strength at 5% strain	kN/m	52
Long-term allowable load in sand silt and clay	kN/m	45.2
Long-term allowable load in well-graded sand	kN/m	43.9
Long-term allowable load in aggregate	kN/m	43.1
Junction strength	kN/m	105

Tasks – Design Summary

REINFORCEMENTS – TYPE AND PULLOUT CHARACTERISTICS - GEOGRIDS

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Size of tire pieces	Tire shred-Sand ratio (by weight)	Confining Pressure (kPa)	Maximum Dry Unit Weight (kN/m ³) (Yoon 2006)	Average dry unit weight in pullout box	Relative compaction (%)	Average Sand-matrix unit weight	Geogrid pullout capacity (kN/m)
Ottawa Sand	25:75	40	18.0	17.4	96.7	17.4	23.8
		70					32.6
		100					42
9.5 mm size chips	25:75	40	15.2	14.5	95.4	16.9	23.6
		70					34.5
		100					40.1
50-100 mm shreds	25:75	40	16.6	15.1	90.8	16.4	19.7
		70					25.6
		100					30.7
100-200 mm shreds	25:75	40	16.5	14.6	88.5	16.0	15.8
		70					22.0
		100					32.1

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THANK YOU

DESIGN SUMMARY FOR THE PRACTICAL USE OF TIRE SHRED-SAND MIXTURES

1.1. Introduction

Various design parameters are required for the practical use of tire shred-sand mixtures. This document provides the essential properties of tire shred-sand mixtures, which can be used as criteria for design when the mixture is used as backfill material for mechanically stabilized earth (MSE) walls. In order to prepare this design summary existing design manuals for MSE walls were used as reference for certain applicable criteria while other properties were determined from laboratory tests. The design summary provides the following:

1. Size characteristics and index properties of tire shreds and sand used to prepare the mixture
2. Mixing Ratio:
 - (i) Conversion from weight ratio to volume mixing ratio and vice-versa
 - (ii) Unit weight and relative compaction requirements at each mixing ratio
 - (iii) Shear strength parameters at each mixing ratio
3. Pullout characteristics for different types of reinforcements embedded in tire shred-sand mixtures.

1.2. Size and, Index and Chemical properties of Tire Shred-Sand Backfill

1.2.1. Sand

Gradation Limits:

The sand used for preparing the mixture should qualify the size criteria prescribed in Table 1.1.

Table 1.1 Gradation limits of the sand to be used in preparing tire shred-sand mixtures (FHWA 2009)

Sieve Size	Percent Passing
4 inches	100
No. 40	0-60
No. 20	0-15

Plasticity Index:

The plasticity index of the sand should not exceed 6 (FHWA 2009).

Apart from the gradation and plasticity index requirements, the sand used in preparing the mixture for backfill should be free of organic and other deleterious materials. The sand should not contain shale or other soft and low-durability particles. The sand should also have a Magnesium Sulfate soundness of less than 30 percent after 4 cycles (FHWA 2009).

Electrochemical Criteria:

The electrochemical criteria for the sand is shown in Table 1.2. These criteria are based on existing recommendations for backfill material for MSE walls. However, tests may need to be conducted to determine the electrochemical requirements for tire shred-sand mixtures.

Table 1.2 Electrochemical criteria for sand (FHWA 2009)

Criteria	Test Method
Resistivity > 300 ohm cm	AASHTO T-288
pH: 5-10	AASHTO T-289
Chlorides < 100 ppm	ASTM D4327
Sulfates < 200 ppm	ASTM D4327
Organic Content – Max. 1%	AASHTO T-267

1.2.2. Tire Shreds

The tire shreds used for preparing the mixture are of size 2 to 4 inches (50 to 100 mm), measured along the longest length between any two points on a given tire shred. The properties of tire shred-sand mixtures presented in this summary correspond to mixtures prepared with tire shreds of size 2 to 4 inches. Other lengths of tire shreds

may be used if properties have been determined for mixtures prepared using the corresponding size of tire shreds.

1.3. Properties of Tire Shred-Sand Mixtures

1.3.1. Weight to Volume Conversion (vice-versa)

The weight ratios can be converted to their corresponding volume mixing ratios using the minimum dry unit weight of pure tire shreds and sand (Balunaini 2009). The minimum unit weight of sand or tire shreds refers to the unit weight of sand or tire shreds measured in an uncompacted state within a compaction mold. Here, it is assumed that the minimum unit weight of pure sand closely resembles the individual unit weight of sand within the mixture. Similarly, it is assumed that the minimum unit weight of tire shreds closely resembles the individual unit weight of tire shreds within the mixture. We will now look at an example for this weight ratio to volume mixing ratio conversion for the tire shred-sand mixture.

Example 1.1:

Consider a weight ratio $= W_{TS} : W_S = 20 : 80$ by weight of tire shreds to sand. W_{Total} is the total weight of the sample. Let $V_{TS} : V_S$ be the ratio by volume of tire shreds to sand. V_{Total} is the total volume occupied by the sample.

From Table 3.1 we know that,

Minimum unit weight of sand (unit weight in uncompacted state), $\gamma_{S,min} = 16.6 \text{ kN/m}^3$

Minimum unit weight of tire shreds (unit weight in uncompacted state), $\gamma_{TS,\min} = 4.1 \text{ kN/m}^3$

Now, from the definition of unit weight,

$$V = \frac{W}{\gamma}$$

The weight ratio considered is 20:80, by weight of tire shreds to sand,

$$\frac{W_{TS}}{W_S} = \frac{20}{80}$$

Combining the above two equations and from the assumption that the minimum unit weights of individual materials are close to the unit weights of individual materials in the mixture,

$$\frac{V_{TS}}{V_S} = \frac{\frac{W_{TS}}{\gamma_{TS,\min}}}{\frac{W_S}{\gamma_{S,\min}}}$$

$$\text{and also, } V_{Total} = V_{TS} + V_S$$

Combining the above two equations

$$\frac{V_{TS}}{V_{Total}} = \frac{\frac{W_{TS}}{\gamma_{TS,\min}}}{\frac{W_{TS}}{\gamma_{TS,\min}} + \frac{W_S}{\gamma_{S,\min}}}$$

Substituting the values for all the quantities on the right hand side of the equation,

$$\frac{V_{TS}}{V_{Total}} = \frac{\frac{20/100}{4.1}}{\frac{20/100}{4.1} + \frac{80/100}{16.6}} = 0.5$$

and also, $V_{Total} = V_{TS} + V_S$

As a result,

$$\frac{V_{TS}}{V_S} = \frac{50}{50}$$

Therefore,

$$\frac{W_{TS}}{W_S} = \frac{20}{80} \equiv \frac{V_{TS}}{V_S} = \frac{50}{50}$$

Hence, a weight ratio of 20:80 converts to a volume ratio of 50:50, tire shreds to sand.

Table shows the conversion of the tire shred-to-sand weight ratios of the mixtures considered in this study, to the corresponding volume mixing ratios

Table 1.3 Conversion from weight ratios to volume ratios calculated using the minimum unit weight of tire shreds and sand

Weight ratio (TS:Sand)	Volume ratio (TS:Sand) (Calculated using $\gamma_{S,min}$ and $\gamma_{TS,min}$)
20:80	50:50
25:75	58:42
35:65	69:31
45:55	77:23

Hence 20:80, 25:75 and 35:65 mixing ratios by weight approximately convert to volume mixing ratios of 50:50, 60:40 and 70:30, tire shreds to sand.

1.3.2. Dry Unit Weight

The dry unit weights of tire shred-sand mixtures, prepared with tire shreds of size 50-100 mm (2 to 4 inches) and Ottawa sand ($D_{50} = 0.384$ mm) at different mixing ratios by weight, are provided in Figure 1.1. Yoon (2006) proposed an optimum mixing ratio of 25:75 by weight of tire shreds to sand ($\sim 60:40$ by volume mixing ratio of tire shreds to sand) that corresponds to the least void ratio. Table 1.4 provides the dry unit weights at the optimum mixing ratio (in terms of volume mixing ratio) and at adjacent mixing ratios, which are most likely to be used in practice.

Figure 1.1 Variation of dry unit weight with percentage of tire shreds in the mixture (by weight) for tire shred sand mixtures prepared with 2 to 4 inches tire shreds and Ottawa sand (Yoon 2006)

Table 1.4 Unit weights of tire shred-sand mixtures (2-4 in shreds + Ottawa sand) at mixing ratios likely to be used in practice

Mixing ratio by weight	Volume mixing ratio	Max. dry unit weight (pcf)
20:80	~50:50	108.8
25:75	~60:40	105.6
35:75	~70:30	90.3

Now, we will look at the unit weights of tire shred-sand mixtures prepared with 50 mm (2 inch) nominal size tire shreds and B-borrow sand (at 4% moisture content) obtained from SR-110 site in Marshall County, Indiana. Figure 1.2 shows the variation of unit weight with tire shred content in the mixture. The below equation can be used to calculate the unit weight of the mixture at different tire shred contents by weight:

$$\gamma = 17.875 - 0.0549(TS) - 0.000629(TS)^2$$

$$\rho = 113.748 - 0.3492(TS) - 0.00400(TS)^2$$

Where, TS is the percentage of tire shreds in the mixture by weight

Table 1.5 provides the unit weights at the optimum mixing ratio (in terms of volume mixing ratio) and at adjacent mixing ratios, which are most likely to be used in practice.

Figure 1.2 Variation of dry unit weight with percentage of tire shreds in the mixture (by weight) for tire shred sand mixtures prepared with 2 inch tire shreds and B-borrow sand

Table 1.5 Unit weights of tire shred-sand mixtures (2 in shreds + B-borrow sand) at mixing ratios likely to be used in practice

Mixing ratio by weight	Volume mixing ratio	Max. dry unit weight (pcf)
25:75	~50:50	103
35:65	~60:40	96
45:65	~70:30	90

It should be noted that the conversions from weight ratio to volume mixing ratio are different in Table 1.4 and 1.5 because of the different size of tire shreds and the different sand used. In Table 1.4 the minimum unit weights of tire shreds and sand are

as assumed in Example 1.1 of Section 1.3.1, while in Table 1.5 the minimum unit weights of tire shreds and sand are assumed to be 31 pcf and 90 pcf respectively. The minimum unit weights are used to perform the weight to volume mixing ratio conversion as shown in Example 1.1.

1.3.3. Shear Strength

The shear strength parameters for mixing ratios that are likely to be used in practice are provided in Table 1.6. These parameters were determined through large scale direct shear tests. The dimensions of the upper box are 1.2 m x 1.0 m x 0.47 m while the dimensions of the lower box are 1.0 m x 1.0 m x 0.5 m. The shear rate was 1 mm/min.

Table 1.6 Shear Strength parameters for tire shred-sand mixtures

Mixing ratio by weight	Mixing ratio by volume	ϕ_c (degrees)	ϕ_p (degrees)	Cohesive intercept (from best fit line), c (kPa)	Corresponding ϕ from best fit line
20:80	~50:50	30.1	31.0	14.5	27.1
25:75	~60:40	30.6	31.1	17.5	28.0
35:75	~70:30	32.0	32.0	10.3	29.6

1.4. Pullout Response

The pullout response of various reinforcements embedded in tire shred-sand mixtures of varying mixing ratio is presented here. The pullout response was determined by conducting laboratory pullout tests on reinforcement ladders (metal straps), metal strips and geogrids embedded in tire shred-sand mixtures. The dimensions of the sample were 1.0 m x 0.38 m x 0.40 m and the effective length of the reinforcement within the box was 0.74 m. The reinforcement was embedded at a depth of 0.2 m from the top of the sample.

1.4.1. Reinforcement Ladders (or Metal Straps)

Figure 1.3 shows the photograph of the reinforcement ladder (metal strap) used for pullout testing that was manufactured by the Reinforced Earth Company. Figures 1.4 and 1.5 show the plan and sectional view of the reinforcement ladder. Table 1.7 shows the summary of results of the pullout testing conducted on reinforcement ladders embedded in tire shred-sand mixtures at different mixing ratios. Using the results, equations were fitted to determine the pullout resistance factor, F^* at different depths. Table 1.8 shows the fitted equations to determine F^* at different depths of the wall. The results can be used with application of minimal caution.

Figure 1.3 Photograph of reinforcement ladder manufactured by The Reinforced Earth Company (metal strap)

Figure 1.4 Reinforcement ladder - plan view

(c)

Figure 1.5 Reinforcement ladder - sectional view of the reinforcement ladder

Table 1.7 Summary of pullout test results conducted on reinforcement ladders (metal straps) embedded in tire shred-sand mixtures (2 to 4 inches tire shreds + Ottawa sand)

Tire shred-Sand mixing ratio (by volume)~	Tire shred-Sand ratio (by weight)	Confining pressure (kPa)	Maximum dry unit weight (kN/m ³) (Yoon 2006)	Average dry unit weight in pullout box (kN/m ³)	Average relative compaction (%)	Average sand-matrix unit weight (kN/m ³)	Reinforcement ladder (metal strap) pullout capacity (kN)	Pullout resistance factor, F*
0:100	0:100	40	18.0	17.2	95.6	17.2	4.2	1.31
		65					4.9	0.97
		90					6.6	0.95
50:50	20:80	40	17.1	15.6	91.2	16.7	6.1	1.91
		65					7.2	1.43
		90					8.3	1.20
60:40	25:75	40	16.6	14.8	89.1	15.8	5.5	1.73
		65					8.0	1.59
		90					9.5	1.38
70:30	35:65	40	14.2	12.3	86.5	12.3	6.4	2.04
		65					9.4	1.88
		90					9.7	1.42

Table 1.8 Equations fitted for determining F^* at any depth for reinforcement ladders embedded in tire shred-sand mixtures

TS : sand mixing ratio (by weight)	Equation fitted between depth (z) and F^*	Coefficient of determination, R^2
20:80	$= - (z - 9.9995)/3.957$ for $0 \leq z < 7.7$ m $= \tan (\square)$ for $z \geq 7.7$ m	0.957
25:75	$= - (z - 17.457)/8.512$ for $0 \leq z < 12.32$ m $= \tan (\square)$ for $z \geq 12.32$ m	0.987
35:65	$= - (z - 14.108)/5.244$ for $0 \leq z < 12.32$ m $= \tan (\square)$ for $z \geq 10.83$ m	0.922

1.4.2. Ribbed-Metal Strip

Figure 1.6 shows the photograph of the ribbed-metal strip used for pullout testing. Figures 1.7 and 1.8 show the plan and sectional view of the ribbed-metal strip manufactured by The Reinforced Earth Company. Table 1.9 shows the summary of results of the pullout testing conducted on ribbed-metal strips embedded in tire shred-sand mixtures prepared using various sizes of tires and Ottawa sand. Using the results, equations can be fitted to determine the pullout resistance factor, F^* at different depths, as shown in the case of reinforcement ladders.

Figure 1.6 Photograph of ribbed-metal strip manufactured by The Reinforced Earth Company

Figure 1.7 Plan view of ribbed-metal strip

Figure 1.8 Sectional view of ribbed-metal strip

Table 1.9 Summary of pullout tests conducted on ribbed-metal strips embedded in tire shred-sand mixtures (varying size of tires + Ottawa sand)

Size of tire pieces	Tire shred-sand ratio (by weight)	Tire shred-sand ratio (by volume)	Confining pressure (kPa)	Maximum dry unit weight (kN/m ³) (Yoon 2006)	Average dry unit weight in pullout box	Relative compaction (%)	Ribbed metal strip pullout capacity (kN)	Pullout resistance factor, F*
Ottawa Sand	0:100	0:100	40	18.0	17.2	95.5	4.4	1.49
			65				5.2	1.08
			90				5.8	0.87
9.5 mm size chips	25:75	50:50	40	15.2	14.3	94.3	3.2	1.08
			65				4.0	0.83
			90				4.9	0.74
50-100 mm	25:75	58:42	40	16.6	14.7	88.5	3.1	1.05
			65				3.7	0.77
			90				4.4	0.66
100-200 mm	25:75	69:31	40	16.5	14.2	86.2	3.0	1.01
			65				3.4	0.71
			90				3.8	0.57

1.4.3. Geogrids

Figure 1.9 shows the UX-1500 MSE geogrids used for pullout testing that were manufactured by Tensar. Table 1.10 provides the properties of the geogrids used for testing. Table 1.11 presents the summary of pullout test results conducted on geogrids embedded in tire shred-sand mixtures prepared with varying sizes of tires and Ottawa sand.

Figure 1.9 UX 1500 MSE geogrid manufactured by Tensar

Table 1.10 Properties of geogrids used in pullout testing (UX 1500 MSE)

Property	unit	Machine Direction (MD) Value
True initial modulus	kN/m	1580
Tensile strength at 5 % strain	kN/m	52
Long-term allowable load in sands, silts and clay	kN/m	45.2
Long-term allowable load in well graded sands	kN/m	43.9
Long-term allowable load in aggregate	kN/m	43.1
Junction strength	kN/m	105

Table 1.11 Summary of results of pullout tests on geogrids embedded in the mixture

Size of shredded tires	Tire shred:sand ratio (by weight)	Confining pressure (kPa)	Pullout capacity (kN/m)
Ottawa Sand	0:100	40	23.8
		70	32.6
		100	42
9.5mm nominal size	25:75	40	23.6
		70	34.5
		100	40.1
50-100mm in length	25:75	40	19.7
		70	25.6
		100	30.7
100-200mm in length	25:75	40	15.1
		70	22.0
		100	32.1

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