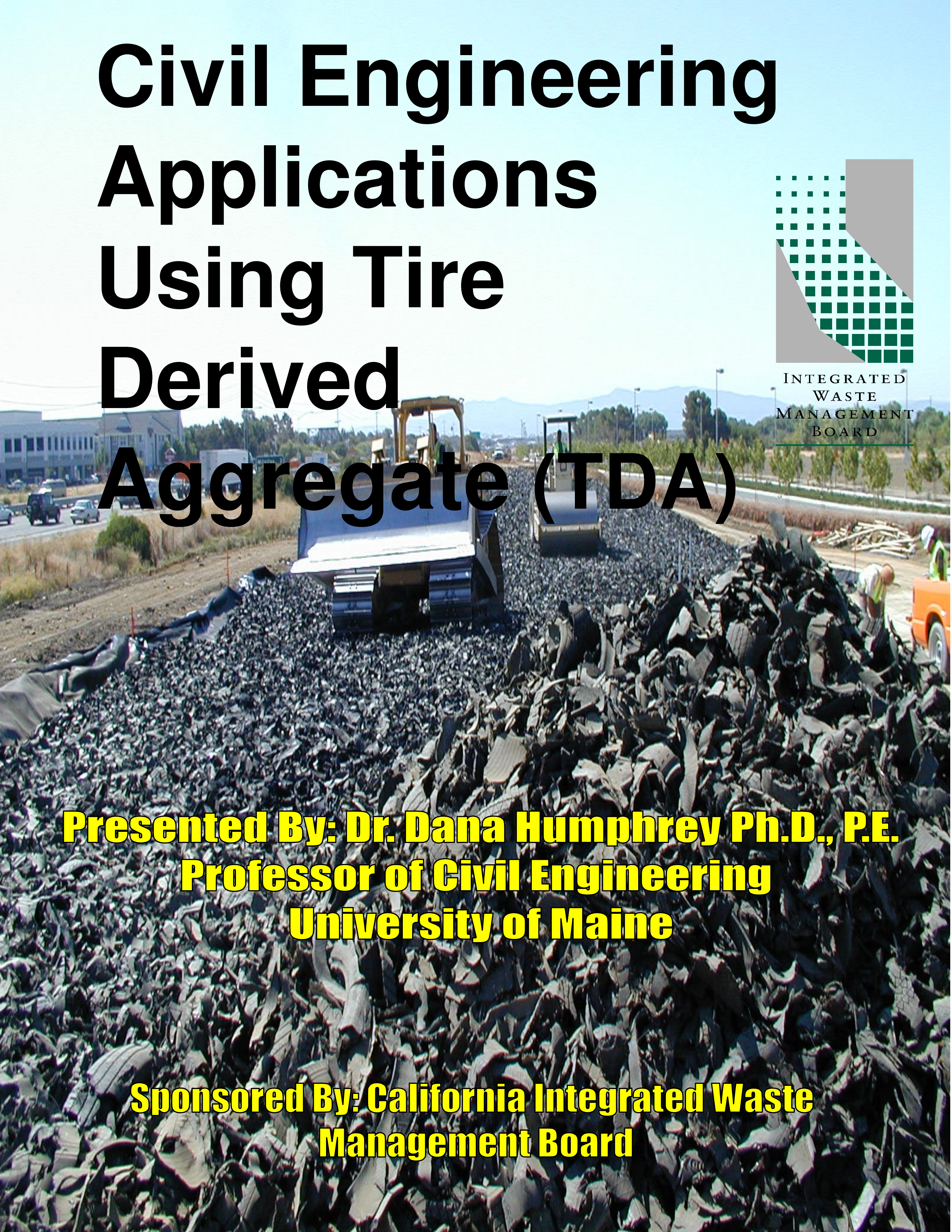
Civil Engineering Applications Using Tire Derived Aggregate (TDA)



INTEGRATED WASTE MANAGEMENT BOARD

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Sponsored By: California Integrated Waste Management Board

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CIVIL ENGINEERING APPLICATIONS OF TIRE SHREDS

Prepared for:
California Integrated Waste Management Board

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I. INTRODUCTION

A. What are tire shreds?

1. Tire shreds are waste tires that have been cut up into 2-in. to 12-in. pieces
2. In general tire shreds are made from a mixture of steel and glass belted tires; unless the source is a tire pile that is decades old, most of the source tires will be steel belted
3. Steel belts are exposed at the cut edges of the tire shreds

B. How are tire shreds made?

1. Tires are cut by knives that rotate at slow speed as shown in Fig. I-1; in general the width of a shred is controlled by the knife spacing; the length of a shred can be as much as the diameter of the tire, although some shredders have hooks on the knives that help pull the tire into the blades and cut the tire lengthwise; an example of shredder blades with hooks is shown in Fig. I-2.

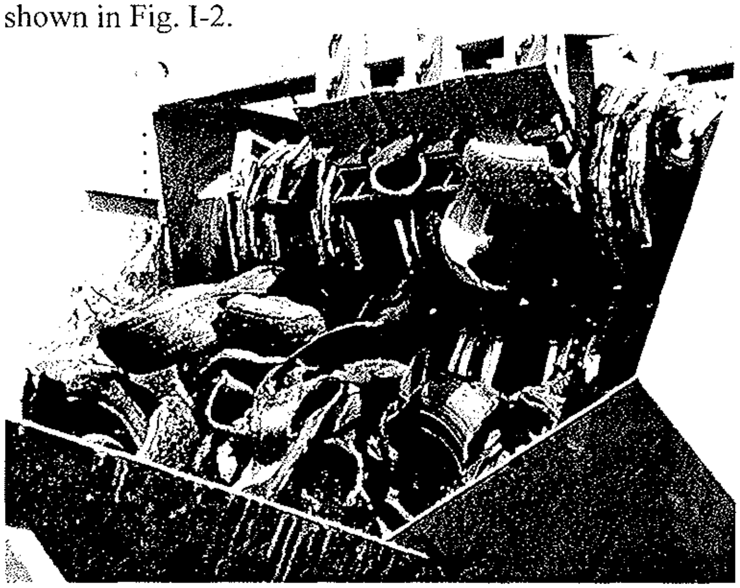

Fig. I-1. Barclay shredder with 6-in. knife spacing.

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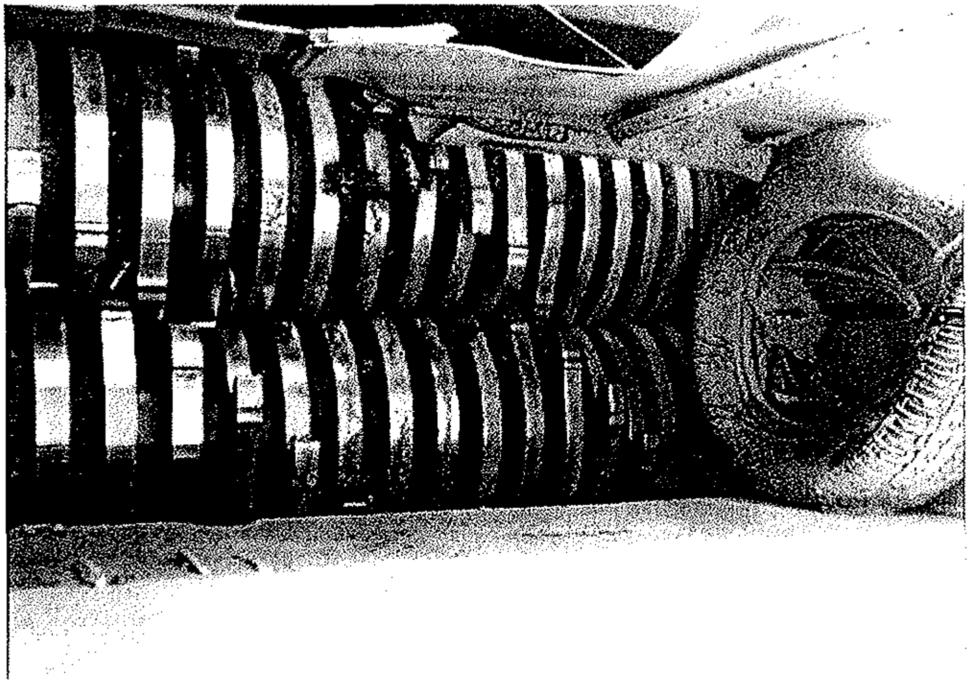

Fig. I-2. Shredder knives on MAC-Saturn shredder showing hooks on knives.

a) Sharp knives (i.e., just after they have been replaced) produce a clean cut with few exposed steel belts

b) Dull knives tend to tear the tire shreds into pieces producing shreds with lots of exposed steel belts; in some cases there is a significant amount of free wire (i.e., wire that is not at least partially embedded in rubber). Dull knives also tend to produce shreds with a larger width since they may not completely separate two pieces.

c) So the amount of exposed steel belts will vary from day-to-day depending on how sharp the knives are

d) In some cases truck and heavy equipment tires are cut into quarters with a segmitizer prior to shredding

e) Hammer mills are also used to produce tire shreds, however they generally produce an excessive amount of exposed steel belt and free wire; this type of machine should not be used to produce shreds for civil engineering applications unless most of the steel belts are removed by magnetic separation

2. Sizing tire shreds

   a) One pass through shredder = rough shreds

   b) Multiple passes through shredder

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c) Tire shreds are sized with rotating screen called a trommel as shown in Fig. I-3 or a classifier made up of parallel bars spaced several inches apart; the bars rotate, carrying the large size pieces off the end of the classifier as shown in Fig. I-4 (also called a star screen)

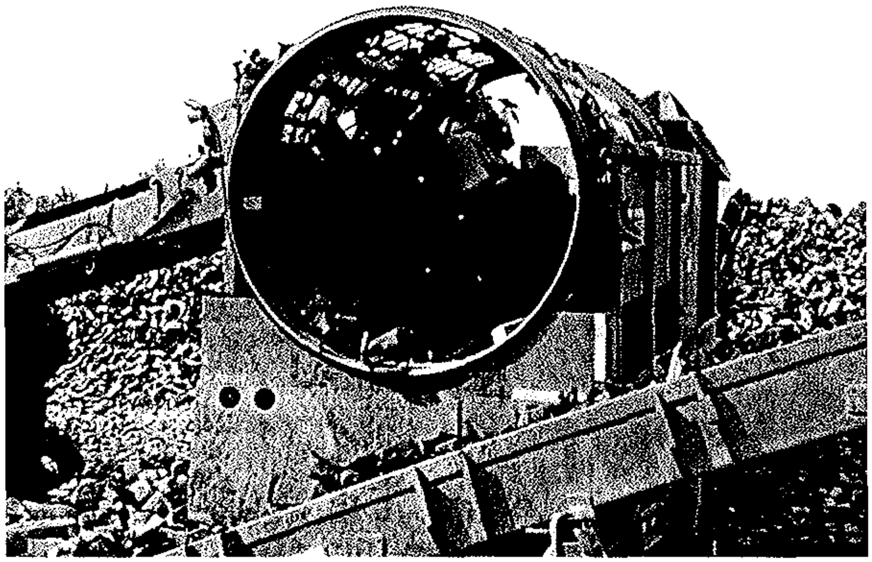

Fig. I-3. Rotating trommel used for sizing tire shreds.

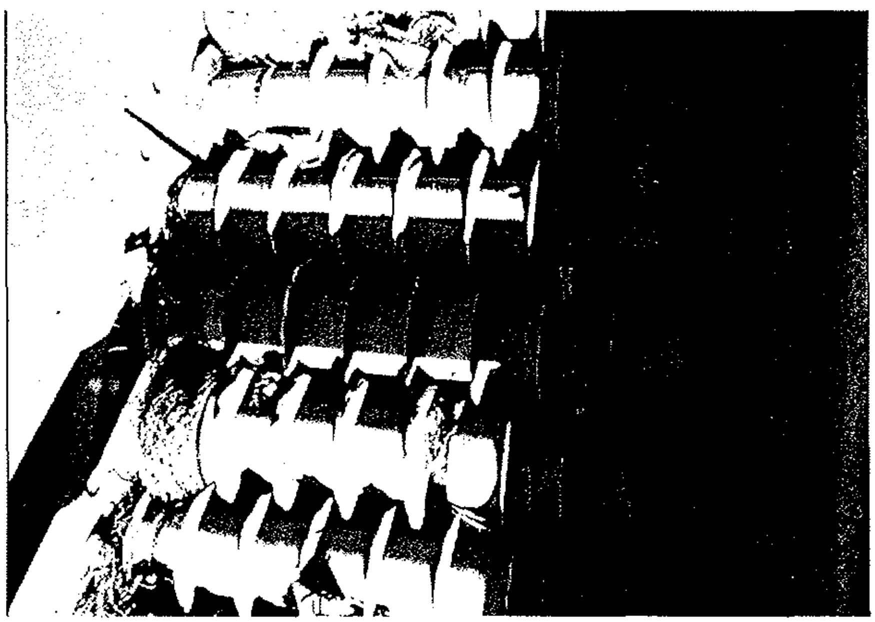

Fig. I-4. Classifier or star screen used for sizing tire shreds.

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3. There are two kinds of wire: bead wire is larger diameter (typically 1/8-in. diameter); and belt wire which is much smaller in diameter

4. Partial removal of steel belts

   a) Debead tires prior to shredding – in general this is too costly for civil engineering applications

   b) Head pulley magnet – the head pulley at the top of a conveyor belt is magnetized

   c) Cross-belt magnet operating over a conveyor belt or vibrating table

5. A by-product is rubber fines – it accumulates under the shredding equipment as shown in Fig. I-5 and is really a mixture of rubber fines, belt wire, and dirt – this material should not be mixed with tire shreds used for civil engineering applications

6. Equipment is portable over the road - can bring the equipment to the pile

Fig. I-5. Mixture of rubber fines, belt wire, and dirt accumulated underneath a conveyor belt.

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C. How many shreds can be used in construction?

1. One cubic yard of compacted tire shred fill contains about 75 tires, so 14-cy dump truck contains 1000 tires -- how many dump truck loads of fill did you use on your last project?

2. Examples

   a) Town road in Richmond, Maine: 20,000 tires in 600-ft of road

   b) Two-lane secondary state highway in North Yarmouth, Maine: 100,000 tires in 400-ft of road

   c) Four-lane primary state highway in T31MD, Maine: 200,000 tires in 400-ft of road

   d) Landslide repair in Wyoming: 650,000 tires

   e) Highway embankment in Virginia: 1.7 million tires

   f) Highway embankment in Portland, Maine: 1.2 million tires

3. Typically one scrap tire is produced per person each year; for some of the New England states with low population, it is entirely possible that several small tire shred projects could use all the scrap tires generated in a year

D. Why use tire shreds?

1. Tire shreds have properties that civil engineers, public works directors, and contractors need

   a) Lightweight (40 to 60 pcf)

   b) Free draining (permeability greater than 10 cm/s)

   c) Low earth pressure (example: 50% lower at base of 16 ft high wall)

   d) Good thermal insulator (8 times better than gravel)

   e) Durable

   f) Compressible

   g) For many applications, they are the cheapest solution

2. Help solve a significant environmental problem

   a) Nationwide there are 850 million scrap tires in open piles; an additional 253 million scrap tires are generated each year, of which 72% are put to some useful purpose (tire derived fuel, civil engineering, manufactured products) the rest are added to the open piles (Associated Press, 1996)

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b) New England has more than its share of tires in stockpiles, some 76 to 111 million!!!! (Maine has 30-60 million; Rhode Island has 34 million; Massachusetts has 5-10 million; Connecticut has 6 million; Vermont has 1 million; information is not available for New Hampshire)

c) Open tire piles present several problems

(1) Fire hazard

(2) Health hazard

(3) Use up valuable landfill space

(4) Ugly scar on our landscape

3. Conserve natural aggregate resources

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II. OVERVIEW OF TIRE SHRED USE IN CONSTRUCTION

A. Lightweight fill

1. Tire shreds have a low unit weight of 40 to 60 pcf; the low end of the range is for a thin tire shred fill with no soil cover; the high end of the range is for a thick tire shred fill with a thick soil cover ---- for comparison, the typical unit weight of gravel is 125 pcf

2. Tire shreds as lightweight fill for embankment construction are needed for two reasons

   a) Slope stability or landslide problems

      (1) These could be caused by weak foundation soils, such as soft clays, or weak bedrock

      (2) Tire shreds are used to increase the stability of an embankment constructed on soft marine clay is shown in Fig. II-1

   b) Excessive settlement caused by weight of embankment

      (1) This most often occurs when there is a large thickness of underlying soft clay

      (2) Tire shreds reduce weight of embankment, thereby reducing settlement as shown in Fig. II-2

B. Conventional fill

1. In this application, the special properties of tire shreds are not needed

2. The driving concern is disposal of tires (75 tires per cubic yard of fill!!!)

3. This is being done for a project in Crawford, Maine. The project will use 300,000 to 700,000 tires in a deep fill section as shown in Fig. II-3. The tires are coming from a nearby pile in Meddybemps, Maine. This project was located way Down East and there was no other economical use for the tires; the cost to Maine DOT is the same as common borrow – the Maine Dept. of Environmental Protection is picking up the rest of the cost.

C. Retaining wall and bridge abutment backfill

1. For conventional walls, tire shreds have two benefits: reduced pressure on the wall and reduced settlement if the wall is founded on compressible soil; typical application is shown in Fig. II-4

   a) Reduced pressures mean cheaper wall

   b) Lightweight fill means less settlement due to underlying compressible soils; less cracking of wall; found wall on spread footing rather than pile foundation

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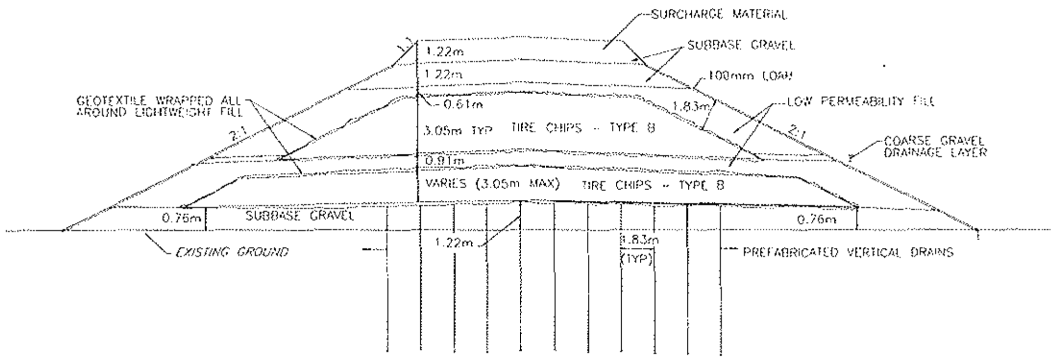

Fig. II-1. Cross section through embankment constructed on soft marine clay at the Portland (Maine) Jetport (Humphrey, et al., 1998)

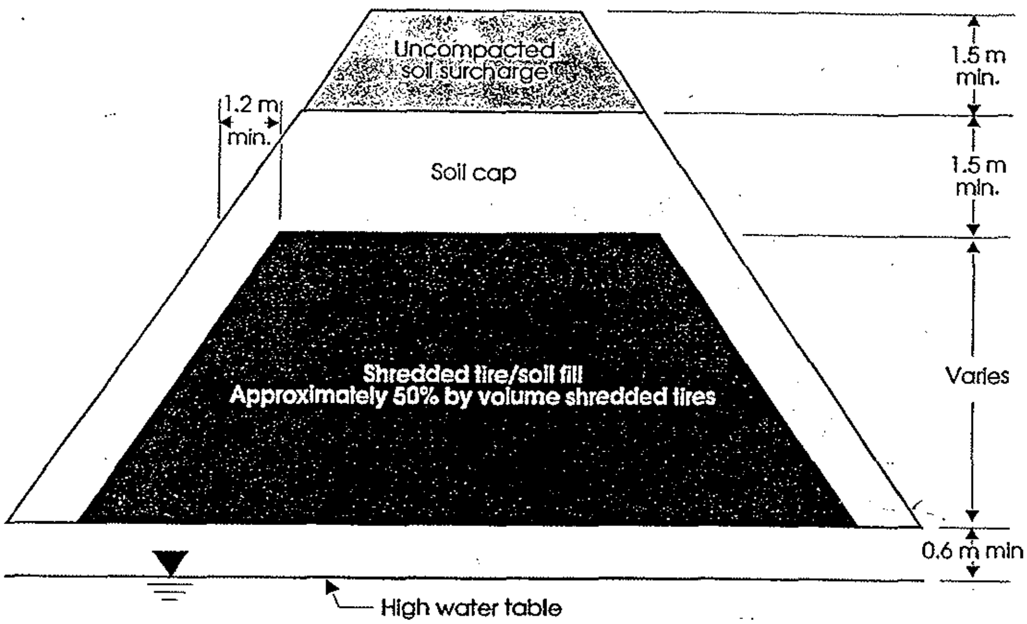

Fig. II-2. Cross section through lightweight tire shred/soil fill used to reduce settlement of embankment constructed in Virginia (Hoppe, 1994)

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Fig. II-3. Tire shreds used as conventional fill in a deep fill section on Rt. 9 in Crawford, Maine.

2. For rigid frame walls (i.e., walls that cannot move away from the backfill), a thin layer of compressible tire shreds, allows that soil backfill to move, mobilizing the soil's strength, and reducing the pressure on the wall; typical application is shown in Fig. II-5

D. Insulation to limit frost penetration

1. Frost penetration beneath roads causes frost heave which can create a bumpy road surface and crack the pavement

2. Loss of strength when subgrade soils thaw is the most critical time of year for a road

3. Tire shreds are about 8 times better than gravel for reducing frost penetration - if subgrade soils don't freeze during winter, there will be no frost heaves and there will be no loss of strength during the spring thaw; typical application is shown in Fig. II-6

E. French drains and drainage layers for roads

1. The permeability of tire shreds is greater than most granular aggregate
2. Use tire shreds for French drains along roadsides or drainage layers beneath roads as shown in Fig. II-7

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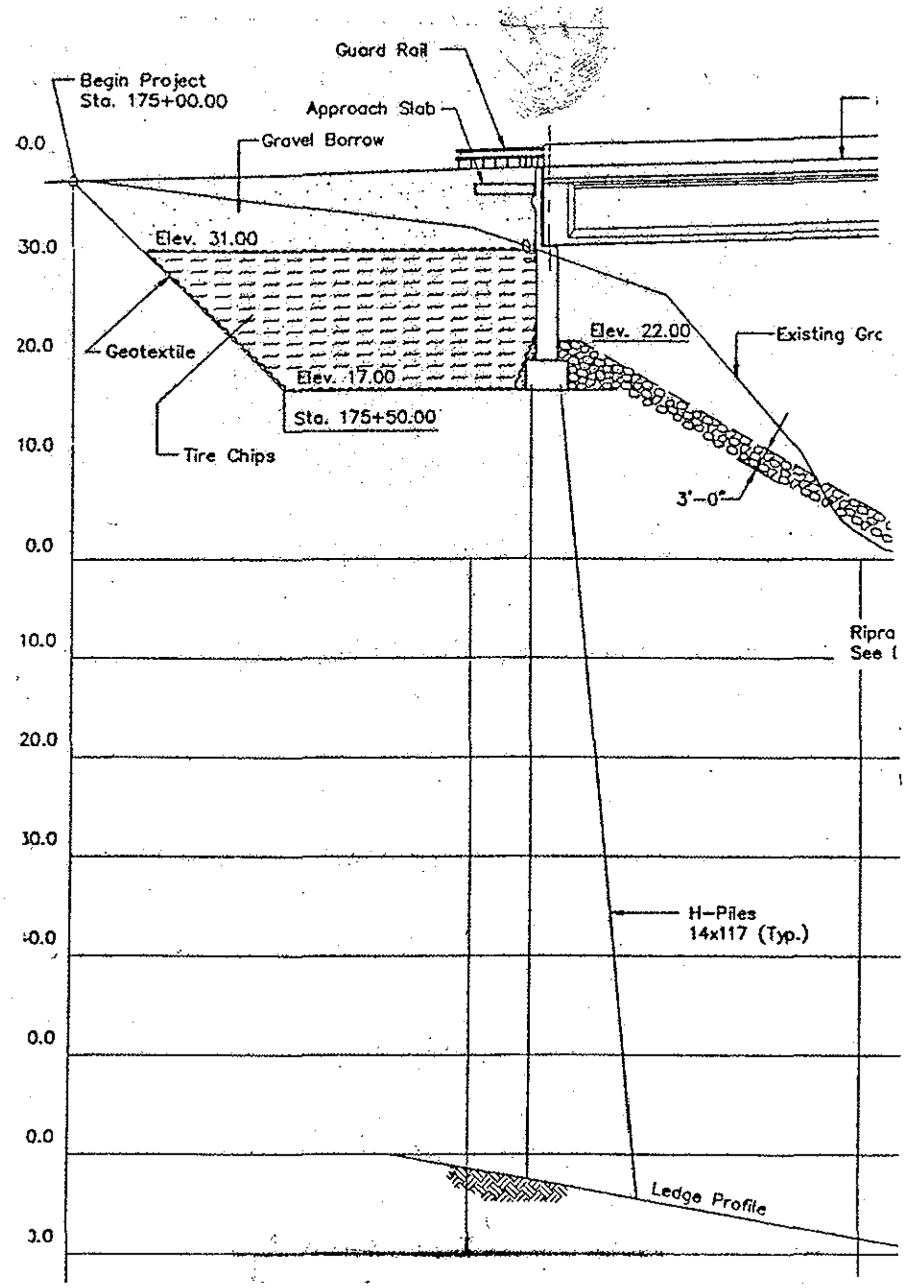

Fig. II-4. Tire shreds used as lightweight backfill on Topsham-Brunswick By-Pass project constructed in 1996 by the Maine DOT

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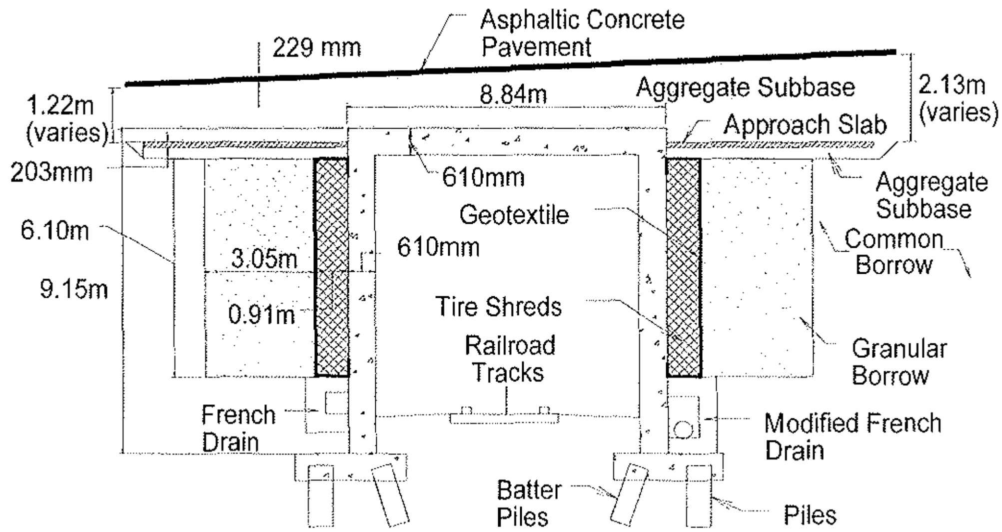

Fig. II-5. Tire shreds used as compressible backfill for rigid frame bridge on Topsham-Brunswick By-Pass project constructed in 1996 by the Maine DOT

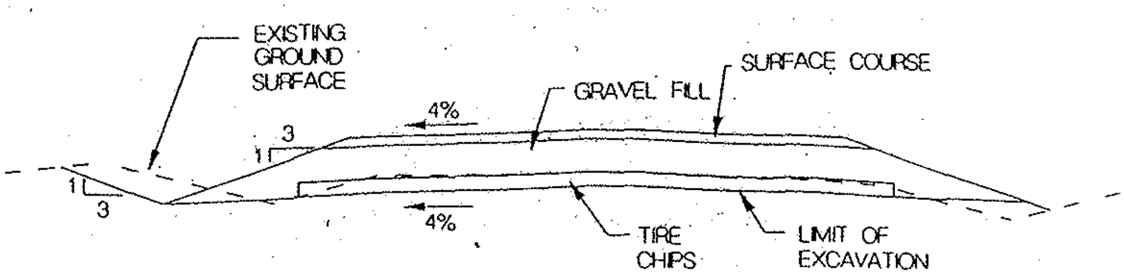

Fig. II-6. Cross section through project in Richmond, Maine where tire shreds were used as thermal insulation to limit depth of frost penetration beneath gravel surfaced road (Humphrey and Eaton, 1995).

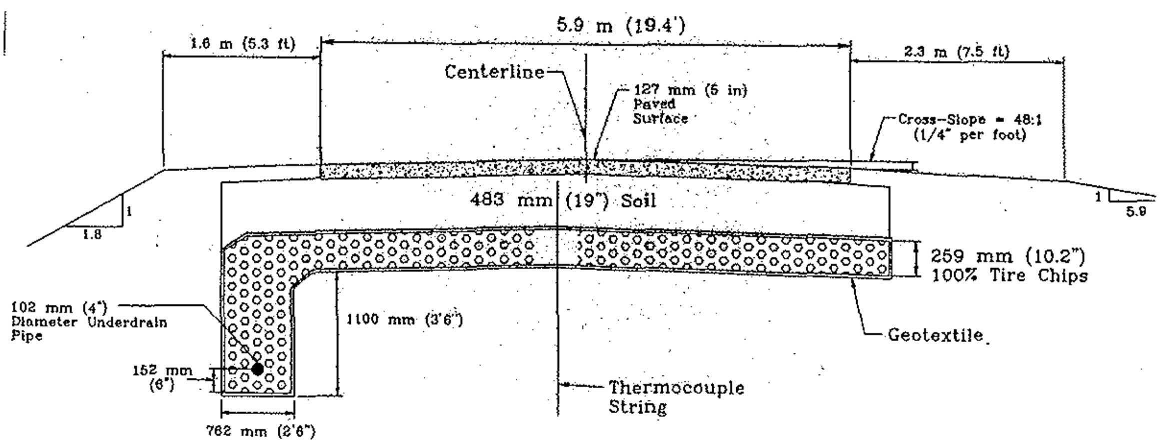

Fig. II-7. Use of tire shreds as edge drain on Witter Farm Road, University of Maine campus.

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E. Uses of whole tires

1. Use to construct retaining walls; system used in California is shown in Fig. II-8 (Richmond and Jackura, 1984; Williams and Weaver, 1987; CalTrans, 1988, Nguyen and Williams, 1984)

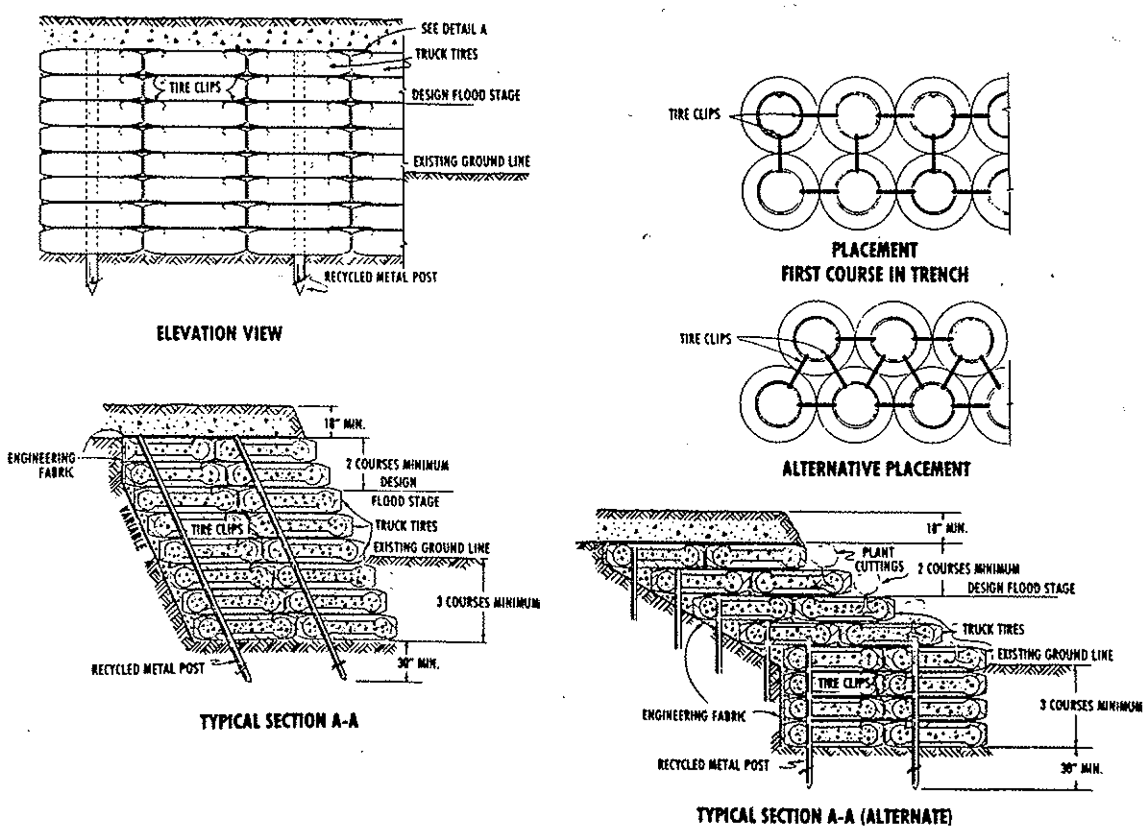

Fig. II-8. Use of whole tires to construct retaining walls (CalTrans, 1988).

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III. ASTM SPECIFICATIONS FOR TIRE SHREDS

A. Status report

1. Worked with Scrap Tire Management Council to develop ASTM D 6270-98, "Standard Practice for Use of Scrap Tires in Civil Engineering Applications"

2. Given final approval in 1998 – it is now being type set by ASTM

3. This is a "Standard Practice" that gives accepted procedures for testing and using tire shreds - but is not a detailed requirement like a "Test Method"

B. Outline of the standard practice is given below

1. Scope

2. Referenced Documents (other ASTM standards)

3. Terminology – standardized definitions

4. Significance and Use – how tire shreds can be used in civil engineering applications

5. Material Characterization – how to measure tire shred properties along with typical values

6. Construction Practices – overview of construction practices

7. Leachate – overview of findings

C. Definition of important terms

1. rubber fines, *n* -- small particles of ground rubber that result as a by-product of producing shredded rubber.

2. tire chips, *n* -- Pieces of scrap tires that have a basic geometrical shape and are generally between 12 mm and 50 mm in size and have most of the wire removed (Syn. chipped tire).

3. tire shreds, *n* -- Pieces of scrap tires that have a basic geometrical shape and are generally between 50 mm and 305 mm in size.

4. rough shred, *n* -- a piece of a shredded tire that is larger than 50 mm by 50 mm by 50 mm , but smaller than 762 mm by 50 mm by 100 mm.

5. The size used for most civil engineering applications are tire shreds, so this is the proper terminology

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IV. ENGINEERING PROPERTIES OF TIRE SHREDS

A. Gradation

1. Tire shreds are generally uniformly graded (i.e., mostly the same size) and their maximum size varies according to the manufacturing process

2. Gradation may be determined in a sieve shaker using the same procedures used for soils (ASTM D 422); the sample size should be large enough to contain a representative selection of particle sizes; since tire shreds are large this requires a large sample size; ASTM D 422 specifies sample size by weight, however, the specific gravity of tire shreds is less than half the values obtained for common earthen materials, so it is permissible to use a minimum weight of test samples that is half of the specified value
3. Typical gradations of tire shreds with 1-in., 3-in. and 12-in. nominal maximum sizes is shown in Fig. IV-1
4. If desired, the percent wire that is not at least partially encased in rubber is determined by manual separation of the wire from the sieved sample and the amount of exposed steel can be measured

B. Specific gravity and water absorption capacity

1. Specific gravity is the ratio of the particle unit weight or unit weight of solids (γ_s) of the tire shreds divided by the unit weight of water (γ_w); thus a material whose unit weight of solids equals the unit weight of water has a specific gravity of 1.000. In equation form the apparent specific gravity (S_a) is $S_a = \gamma_s/\gamma_w$
2. Absorption capacity is the amount of water absorbed onto the surface of the particles; it is expressed as the percent water based on the dry weight of the particles
3. Both are determined in accordance with ASTM C 127. However, the specific gravity of tire shreds is less than half the values obtained for common earthen coarse aggregate, so it is permissible to use a minimum weight of test sample that is half of the specified value
4. The specific gravities and water absorption capacities of tire shreds reported by several investigators are summarized in Table IV-1. The table is sorted by the following tire shred categories: glass belted, steel belted, and mixture of glass and steel belted. The apparent specific gravities range from 1.02 to 1.27. Tire shreds with specific gravities in the high end of the range generally have a high proportion of steel belted tire shreds. The specific gravities for soils are typically 2.60-2.80, so tire shreds are less than half!!!
5. Water absorption capacities ranged from 2 to 4.3 %, except for one investigator who reported a value of 9.5 %.

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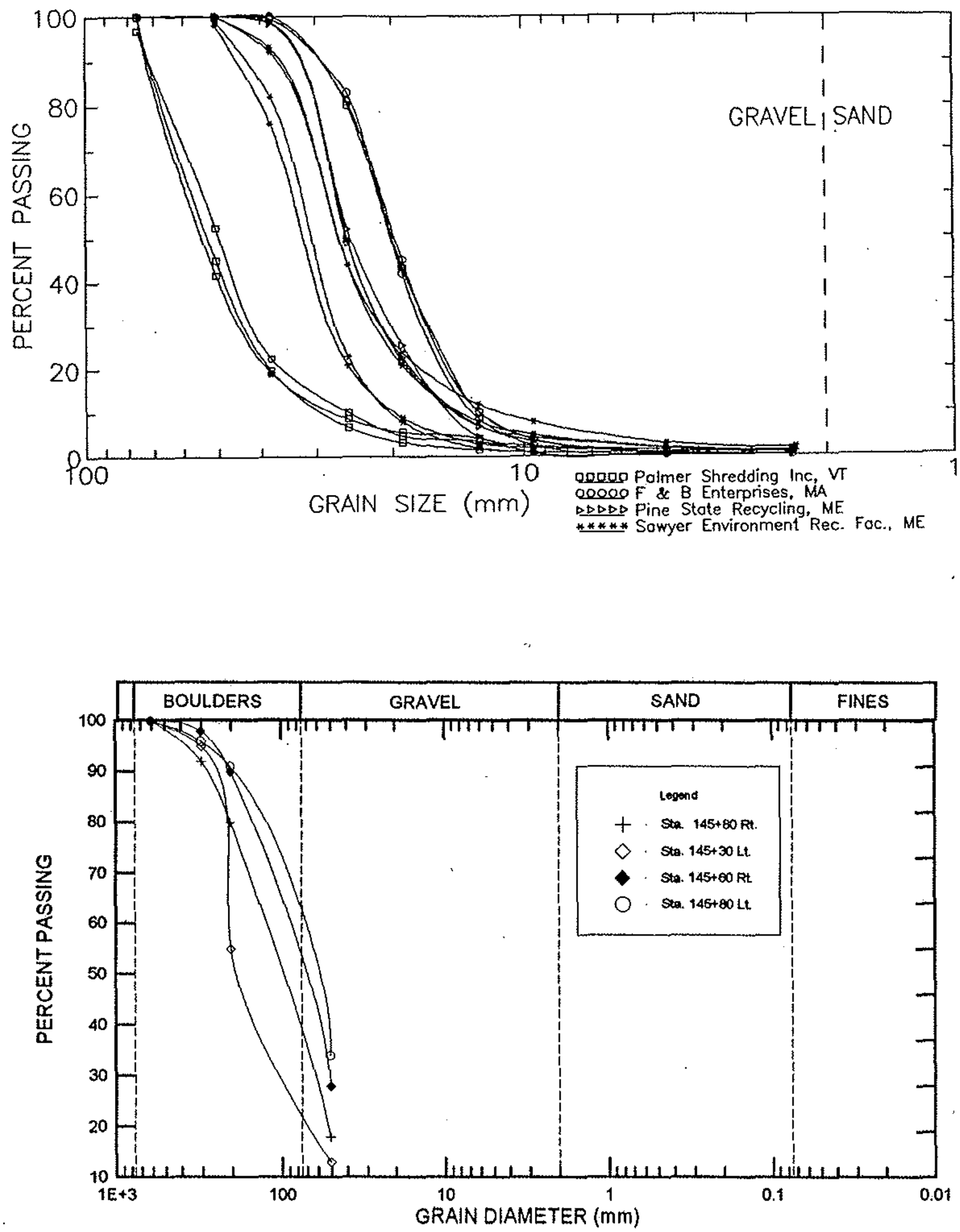

Fig. IV-1. Gradations of tire shreds with 1-in., 3-in. and 12-in. nominal maximum sizes.

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Table IV-1. Summary of specific gravities and water absorption capacity.

Tire shred type	Specific gravity			Water absorption capacity (%)	Reference
	Bulk	Saturated surface dry	Apparent		
Glass belted	----	----	1.14	3.8	Humphrey et al. (1992)
Glass belted	0.98	1.02	1.02	4	Manion & Humphrey (1992)
Steel belted	1.06	1.01	1.10	4	Manion & Humphrey (1992)
Mixture	1.06	1.16	1.18	9.5	Bressette (1984)
Mixture (Pine State)	----	----	1.24	2	Humphrey et al. (1992)
Mixture (Palmer)	----	----	1.27	2	Humphrey et al. (1992)
Mixture (Sawyer)	----	----	1.23	4.3	Humphrey et al. (1992)
Mixture	1.01	1.05	1.05	4	Manion & Humphrey (1992)
Mixture	----	0.88 to 1.13	----	----	Ahmed (1993)

C. Compacted unit weight

1. The 6-in. diameter compaction mold used for soils is restricted to materials having no more than 30% retained on the 3/4 in. sieve (ASTM D 698 and D 1557) - but, the maximum particle size for tire shred fill is always has more than 30% retained on the 3/4-in. sieve, so test procedures used for soils are not directly applicable to tire shreds

2. For 3-in. maximum size tire shreds use a 10-in. or 12-in. diameter mold; the larger mold requires that the number of layers and/or the number of blows of the rammer per layer be increased to produce the desired compactive energy per unit volume; no one has done compaction tests on tire shreds larger than about 3-in.

3. Effect of compactive energy per unit volume

   a) Studies have used compactive energies ranging from 60% of standard Proctor (ASTM D 698) which works out to 7,425 ft-lb/ft^3 to 100% of modified Proctor (ASTM D 1557) which specifies an energy of 56,250 ft-lb/ft^3

   b) Manion and Humphrey (1992) showed that compactive energy has only a small effect on the resulting dry unit weight - so for convenience you probably want to use 60% of standard Proctor energy

4. Manion and Humphrey (1992) also found that compacted dry unit weights were about the same for air dried samples and saturated surface dry samples, thus, unlike soils, water content does not affect the compaction properties of tire shreds - so for convenience you probably want to do your compaction tests on air dried tire shreds

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5. Laboratory compacted dry unit weights of tire shreds reported by several investigators are summarized in Table IV-2. Tire shreds dumped loosely into the compaction mold typically have dry unit weights between 21 and 31 pcf. For compacted samples, the compaction energy had only a small effect on the resulting dry unit weight. Compacted dry unit weights ranged between 38 and 43 pcf, expect for the results reported by Edil and Bosscher (1992, 1994) who obtained lower values. For comparison, the compacted dry unit weight of soils is typically 125 pcf, thus the dry unit weight of tire shreds is about 1/3 that for soils. However, when picking a design value of dry unit weight for your next project, don't forget that tire shreds are compressible. Thus, the unit weight, after being compressed by the weight of overlying soil and tire shreds will be greater than the laboratory compacted unit weights given in the table - more on this later

6. The laboratory compacted unit weights of tire shred/soil mixtures have also been determined. Of course, the more soil you mix with the tire shreds, the higher the unit weight. Edil and Bosscher (1992, 1994) mixed tire shreds with a maximum size of 3 in. with three soil types: (1) outwash sand; (2) casting sand; and (3) clay. Ahmed (1993) and Ahmed and Lovell (1993) used tire shreds with either a 1-in. or 2-in. maximum size mixed with two soil types: (1) medium to fine, uniformly graded Ottawa sand; and (2) fine grained glacial till with a Unified Soil Classification of CL-ML which is locally known as "Crosby Till". The results of these studies are summarized in Fig. IV-2.

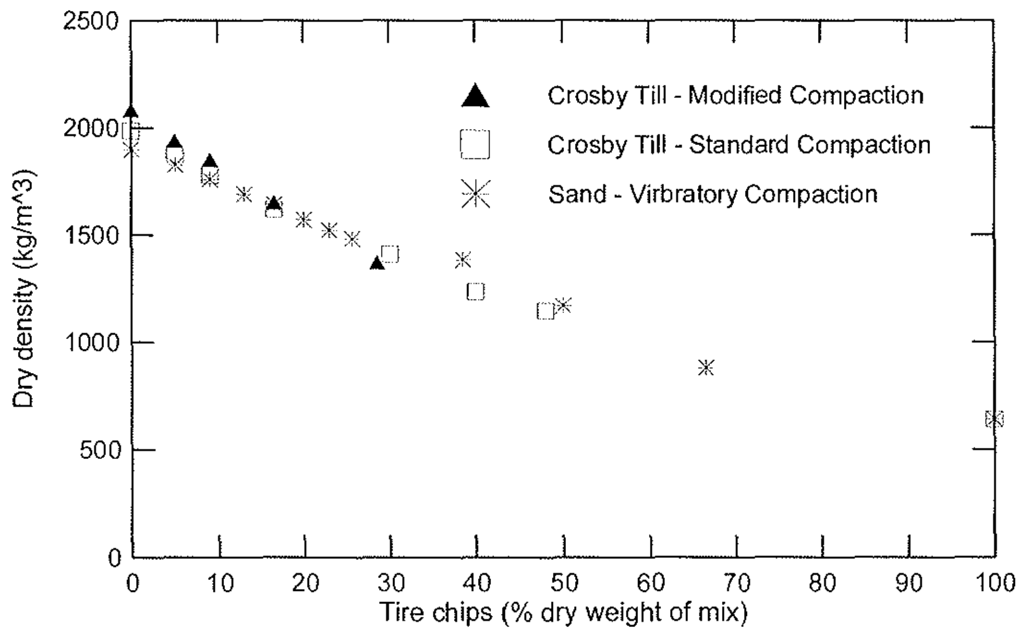

Fig. IV-2. Comparison of compacted dry density of mixtures of tire shreds with Ottawa sand and Crosby till (Ahmed, 1993)

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Table IV-2. Summary of laboratory dry unit weights of tire shreds.

Compaction method[a]	Particle size (in.)	Tire shred type	Source of tire shreds	Dry unit weight (pcf)	Reference
Loose	3	Mixed	Palmer Shredding	21.3	(2)
Loose	2	Mixed	Pine State Recycling	30.1	(2)
Loose	1	Glass	F & B Enterprises	30.9	(2)
Loose	2	Mixed	Sawyer Environmental	25.5	(1)
Loose	2	Mixed	------	29.1	(5)
Loose	1	Mixed	------	30.5	(5)
Vibration	1	Mixed	------	31.0	(5)
Vibration	0.5	Mixed	------	29.5	(5)
50% Standard	1	Mixed	------	38.3	(5)
50% Standard	0.5	Mixed	------	40.0	(5)
60% Standard	3	Mixed	Palmer Shredding	38.7	(2)
60% Standard	2	Mixed	Pine State Recycling	40.1	(2)
60% Standard	1	Glass	F & B Enterprises	38.6	(2)
60% Standard	2	Mixed	Sawyer Environmental	39.0	(1)
Standard	2	Mixed	Sawyer Environmental	39.9	(1)
Standard	2	Mixed	------	39.6	(5)
Standard	1.5	Mixed	------	40.2	(5)
Standard	1	Mixed	------	40.7	(5)
Standard	0.5	Mixed	------	39.5	(5)
Standard	3	------	Rodefeld	37.1[b]	(4)
Standard	3	------	Rodefeld	34.9[c]	(4)
Modified	2	Mixed	Sawyer Environmental	41.2	(1)
Modified	2	Mixed	------	41.7	(5)
Modified	1	Mixed	------	42.7	(5)
----	2	Mixed	------	26 to 36	(3)

Notes: a. Compaction methods:

Loose = no compaction; tire shreds loosely dumped into compaction mold
Vibration = Method D 4253
50% Standard=Impact compaction with compaction energy of 6,188 ft-lb/ft^3
60% Standard=Impact compaction with compaction energy of 7,425 ft-lb/ft^3
Standard = Impact compaction with compaction energy of 12,375 ft-lb/ft^3
Modified = Impact compaction with compaction energy of 56,250 ft-lb/ft^3

b. 6-in. diameter mold compacted by 10-lb rammer falling 12 in.
c. 12-in. diameter mold compacted by 60-lb rammer falling 18 in.

References:
(1) Manion and Humphrey (1992); Humphrey and Manion (1992)
(2) Humphrey, et al. (1992, 1993); Humphrey and Sandford (1993)
(3) Bressette (1984)
(4) Edil and Bosscher (1992, 1994)
(5) Ahmed (1993); Ahmed and Lovell (1993)

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D. Compressibility

1. We need to know the compressibility of tire shreds for three reasons:

   a) Settlement that will occur during construction and in the first month or two after fill is placed due to weight of overlying tire shreds and soil - even though is can be large for tire shreds, this is something we can plan for and accommodate with our design

   b) In-place unit weight of compressed tire shreds

   c) Settlement or deflections caused by a temporary load after construction is completed; an example is deflections of pavement underlain by tire shred fill every time a vehicle drives over it

2. The compressibility of tire shreds and tire shred/soil mixtures have been measured by placing tire shreds in containers with diameters ranging from 6 in. to 29 in. and then measuring the vertical strain caused by an increasing vertical stress (Manion and Humphrey, 1992; Humphrey and Manion, 1992; Humphrey, et al., 1993; Humphrey and Sandford, 1993; Edil and Bosscher, 1992, 1994; Ahmed, 1993; Ahmed and Lovell, 1993; Drescher and Newcomb, 1994; Nickels, 1995). Typical compressibility curves for 3-in. tire shreds at low stress ranges is shown in Fig. IV-3 and at high stress ranges in Fig. IV-4. It is seen that compressibility decreases as stress level increases. The compressibilities from several studies are summarized in Table IV-3

3. The compressibility of mixtures of tire shreds and soil has been measured by: Manion and Humphrey (1992), Edil and Bosscher (1992, 1994), Ahmed (1993), and Ahmed and Lovell (1993). Compressibility decreased as the percent tire shreds in the mix decreased. Typical compressibility curves for tire shred/gravel mixtures are shown in Fig. IV-5

4. Caution should be used in interpreting the compressibility results from most studies - except for the studies noted below, they underestimate the compressibility of tire shreds - underestimating compressibility is an unconservative error - a bad thing

   a) In most studies the ratio of the initial sample height to sample diameter was greater than 1. This leads to concerns that a significant portion of the applied vertical stress could be transferred to the walls of the container by friction. This effect was measured by Manion and Humphrey (1992), Humphrey and Manion (1992), Humphrey, et al. (1993), Humphrey and Sandford (1993), and Nickels (1995).

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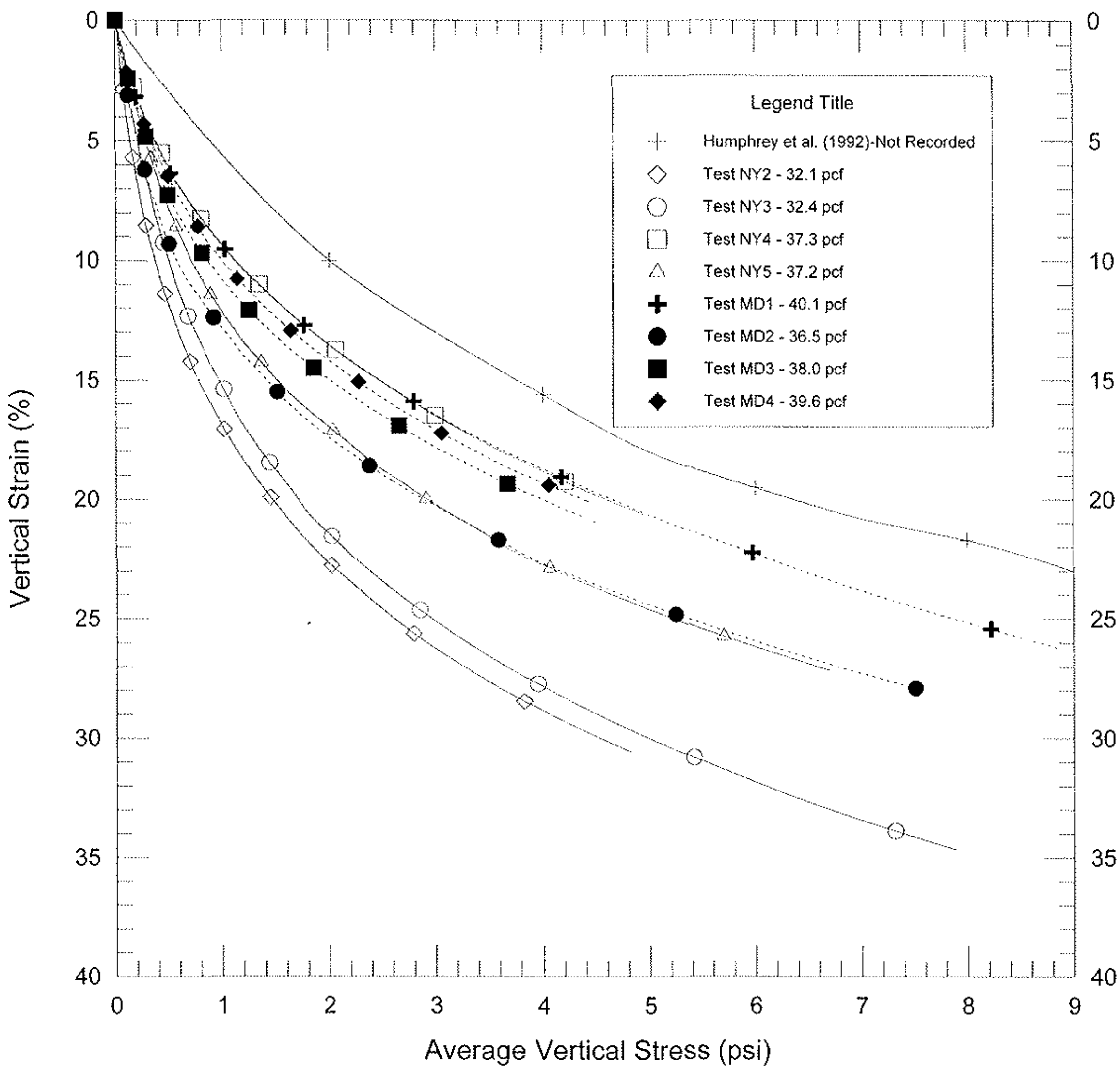

Fig. IV-3. Compressibility of 3-in. minus tire shreds at low stresses (Nickels, 1995)

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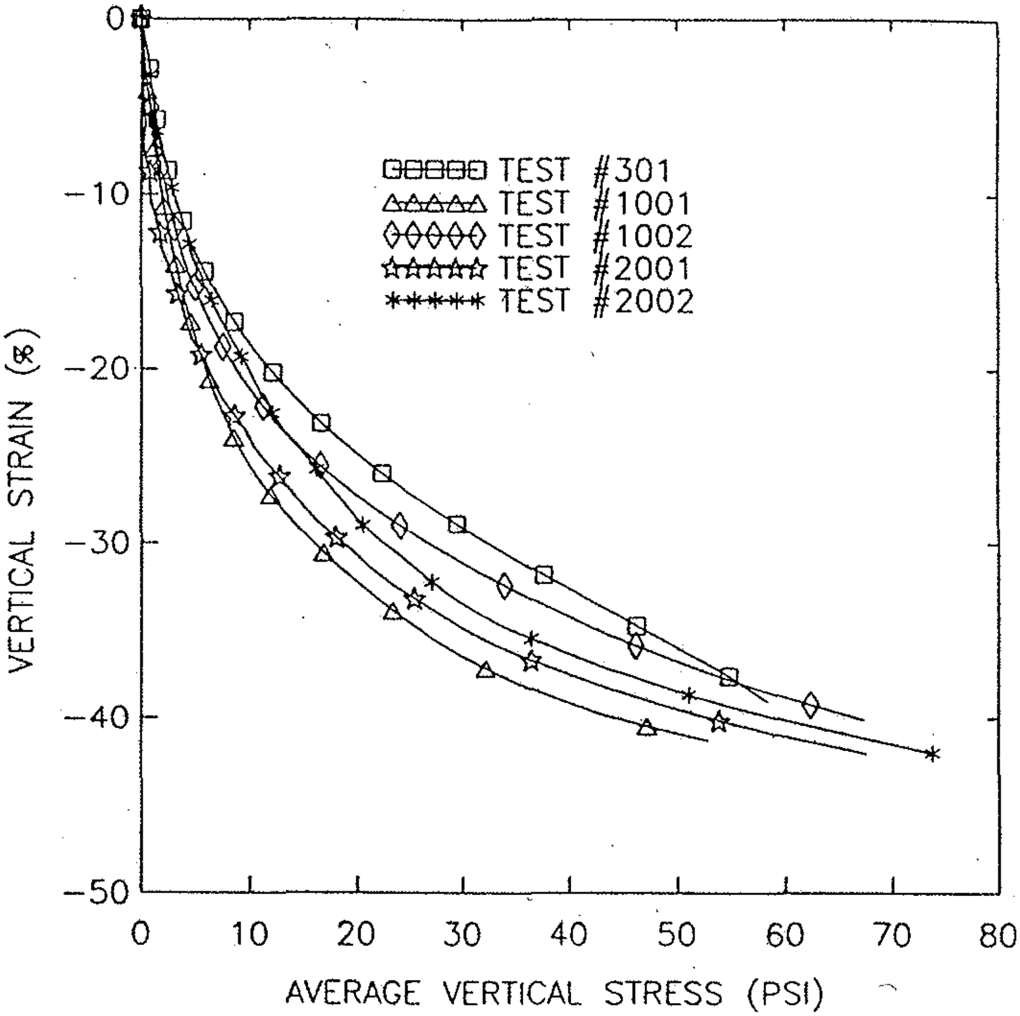

Fig. IV-4. Compressibility of 3-in. minus tire shreds at high stresses (Manion and Humphrey, 1992)

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Table IV-3. Compressibility on initial loading.

Particle size (in.)	Tire shred type	Tire shred source	Initial dry unit weight (pcf)	Vertical strain (%) at indicated vertical stress (psi)					Reference
				1.45	3.63	7.25	14.5	29.0	
3	Mixed	Palmer	Compacted	7 to 11	16 to 21	23 to 27	30 to 34	38 to 41	(2)
2	Mixed	Pine State	Compacted	8 to 14	15 to 20	21 to 26	27 to 32	33 to 37	(2)
1	Glass	F & B	Compacted	5 to 10	11 to 16	18 to 22	26 to 28	33 to 35	(2)
2	Mixed	Sawyer	Compacted	5 to 10	13 to 18	17 to 23	22 to 30	29 to 37	(1)
	Mixed		Compacted	4 to 5	8 to 11	13 to 16	18 to 23	27	(3)
3	Mixed	Pine State	32 to 42	12 to 20	18 to 28	----	----	----	(5)
2	Mixed	Pine State	Loose	18	34	41	46	52	(2)
1	Mixed	F & B	Loose	8	18	28	37	45	(2)
	----		Loose	9	12 to 17	17 to 24	24 to 31	30 to 38	(4)

Reference: (1) Manion & Humphrey (1992)
(2) Humphrey, et al. (1992)
(3) Ahmed (1993)
(4) Drescher & Newcomb (1994)
(5) Nickels (1995)

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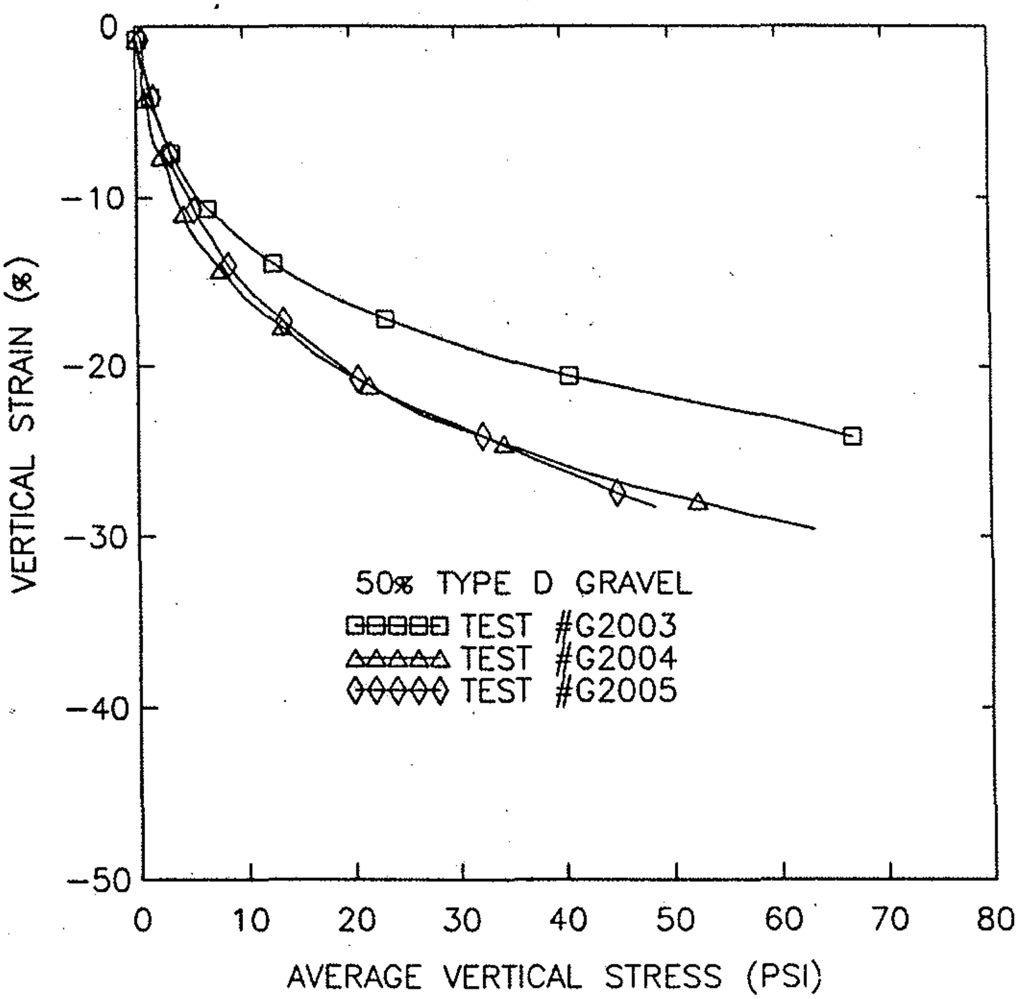

Fig. IV-5. Compressibility of 50-50 mixture (by weight) of tire shreds and gravel (Manion and Humphrey, 1992)

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b) Nickels (1995) used a 13-in. diameter high density polyethylene (HDPE) compression container with side walls lubricated with pump grease. Load cells were used to measure the vertical stress at the top σ_{top} and bottom σ_{bot} of the sample. The test apparatus is illustrated in Fig. IV-6. For the first cycle of loading at an average vertical stress $[(\sigma_{top} + \sigma_{bot})/2]$ of 5 psi, σ_{bot} was between 15.1 and 19.1% less than σ_{top}. If the stress transferred to the walls of the container is not accounted for, the compressibility of the tire shreds will be underestimated.

c) When performing compressibility tests on tire shreds and tire shred/soil mixtures the container should have a sufficient diameter to accommodate the size tire shreds being tested, the inside of the container should be lubricated to reduce the portion of the applied load that is transmitted by side friction from the sample to the container, and the vertical stress at the top and the bottom of the sample should be measured so that the average vertical stress in the sample can be computed.

5. Using compressibility results to determine the in-place moist unit weight of tire shreds after they have been compressed under the weight of overlying tire shreds and soil.

a) Step 1. From laboratory compaction tests or typical values determine the initial uncompressed, compacted dry unit weight of tire shreds (γ_{di}) (for shreds with a 3-in. maximum size, use 40 pcf)

b) Step 2. Estimate the in-place water content of tire shreds (w) and use this to determine the initial uncompressed, compacted total (moist) unit weight of tire shreds (γ_{ti})

$$\gamma_{ti} = \gamma_{di}\,(1+w)$$

Unless better information is available, use w = 3 or 4 %

c) Step 3. Determine vertical stress in center of tire shred layer ($\sigma_{v\text{-}center}$). To do this you need to make a first guess of the compressed unit weight of tire shreds (γ_{tc}; 50 pcf is suggested for the first guess).

$$\sigma_{v\text{-}center} = t_{soil}(\gamma_{t\text{-}soil}) + (t_{shreds}/2)(\gamma_{tc})$$

where: t_{soil} = thickness of overlying soil layer
$\gamma_{t\text{-}soil}$ = total (moist) unit weight of overlying soil
t_{shreds} = compressed thickness of tire shred layer
(Note: In the equation, the thickness of the tire shred layer is divided by 2 since we are computing the stress in the center of the layer)

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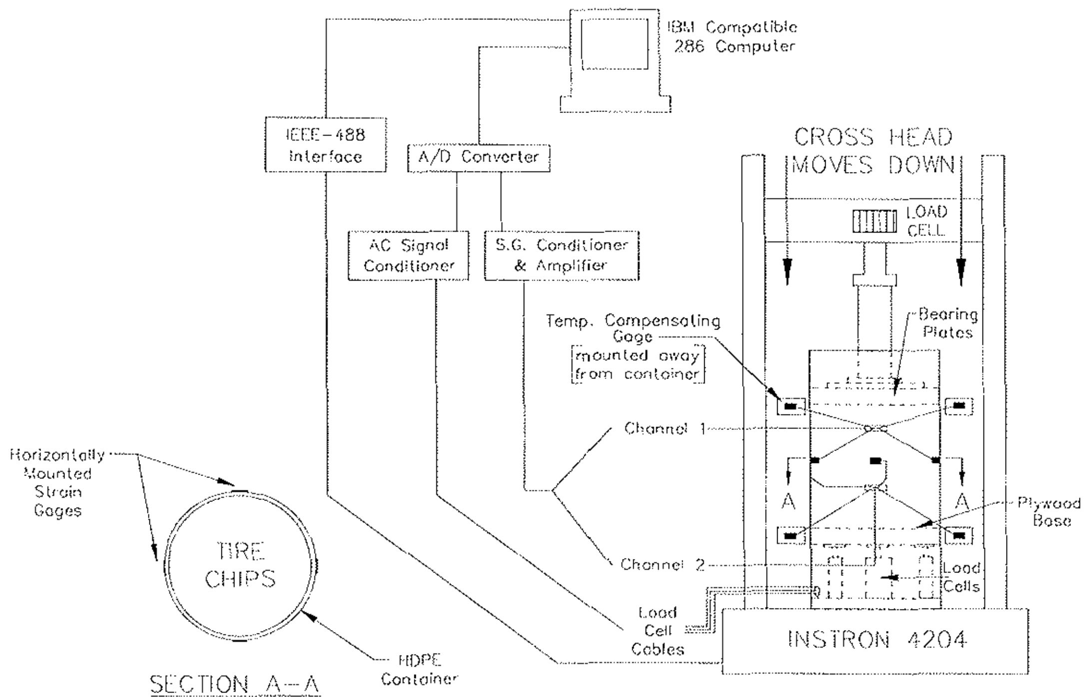

Fig. IV-6. Compressibility apparatus used by Nickels (1995).

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d) Step 4. Determine the percent compression (ε_v) using $\sigma_{v\text{-center}}$ and the measured laboratory compressibility of the tire shreds; for shreds with a 3-in. maximum size, use Fig. IV-3

e) Step 5. Determine the compressed moist unit weight of the tire shreds

$$\gamma_{tc} = \gamma_{ti}/(1\text{-}\varepsilon_v)$$

f) Example: A layer of 3-in. maximum size shreds with a compressed thickness of 3 ft will be covered by 4 ft of soil with a unit weight of 125 pcf. Find the compressed total unit weight of the tire shreds

For 3-in. maximum size shreds, an uncompressed dry unit weight of 40 pcf and water content of 4% are reasonable; thus, the moist (total) unit weight is 40 pcf (1+0.04) = 41.6 pcf.

The vertical stress in the center of the tire shred layer, using 50 pcf as the first guess of the compressed unit weight of the tire shreds $\sigma_{v\text{-center}}$ = (4 ft)(125 pcf) + (3ft/2)(50 pcf) = 575 pcf = 4.00 psi.

From Fig. IV-3, tests with an initial unit weight of about 40 pcf (Tests MD1 and MD4) have a vertical strain of about ε_v = 19%

So the compressed total (moist) unit weight of tire shreds for this project is 41.6 pcf /(1-0.19) = 51 pcf; this is close enough to the 50 pcf assumed as the first guess above – no need to do another iteration.

g) For large size shreds there are no laboratory compaction or compressibility data, so it is necessary to estimate the unit weight of tire shreds from field results of previous projects - field unit weights for constructed projects are determined by taking the total tonnage of tire shreds delivered to the project and dividing by the compressed volume. For a project recently constructed near the Portland (Maine) Jetport, the final in-place unit weight of shreds with a 12-in. maximum size was 49 pcf (see Fig. II-1 for a cross section of this project). The final density of a project constructed in Oregon with 12-in. maximum size shreds (14 ft of shreds covered by 4.9 ft of soil) was 53 pcf (Upton and Machan, 1993).

6. Using compressibility data to estimate the compression of the tire shred layer due to placement of the overlying soil cover. This is used to

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determine the overbuild of the tire shred layer that is needed to result in a layer with the desired compressed thickness

a) Step 1. Determine the final in-place total unit weight of tire shreds using the procedure outlined above. (see the above procedure for definitions of variables)

b) Step 2. Determine the vertical stress in the center of the tire shred layers due to just the weight of the tire shreds with no soil cover.

$$\sigma_{v\text{-}0} = (t_{shreds}/2)\ [(\gamma_{ti} + \gamma_{tc})/2]$$

In this equation, the average is taken between the initial (uncompressed) and final (compressed) unit weights of the tire shreds since the unit weight of the shreds before placing the overlying soil cover is between these two values. (A more accurate calculation of the unit weight before placement of the soil cover is possible, but probably not worth the effort).

c) Step 3. Determine vertical stress in center of tire shred layer after placement of the soil cover ($\sigma_{v\text{-}center}$).

$$\sigma_{v\text{-}center} = t_{soil}(\gamma_{t\text{-}soil}) + (t_{shreds}/2)(\gamma_{tc})$$

d) Step 4. Using compressibility data for tire shreds determine the vertical strain corresponding to $\sigma_{v\text{-}0}$, which we will call ε_{vo}, and corresponding to $\sigma_{v\text{-}center}$, which we will call ε_{vf}; for shreds with a 3-in. maximum size use Fig. IV-3.

e) Step 5. The overbuild (OB) required to compensate for compression of the tire shred layer under the weight of the overlying soil cover is given by

$$OB = t_{shreds}(\varepsilon_{vf} - \varepsilon_{v0})$$

f) Example For the example given in the previous section, compute the required overbuild so that the resulting compressed thickness of the tire shred layer is 3 ft

The compressed unit weight of tire shreds was already computed in the previous example

The vertical stress in the center of the tire shred layer before placement of the soil cover is (3 ft/2) [(41.6 + 51)/2] = 69.5 psf = 0.48 psi

The vertical stress in the center of the tire shred layer after placement of the soil cover is = (4 ft)(125 pcf) + (3ft/2)(51 pcf) = 577 pcf = 4.00 psi

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From Figure IV-3, tests with an initial unit weight of about 40 pcf (Tests MD1 and MD4) have a vertical strain of about $\varepsilon_{v0} = 6.5\%$ at a stress of 0.48 psi and $\varepsilon_{vf} = 19\%$ at a stress of 4.00 psi

The required overbuild is therefore 3 ft (0.19-0.065) = 0.38 ft = 4.5 in, say 4 in.

E. Resilient modulus

1. The resilient modulus is used to describe the compressibility of tire shreds under a moving vehicle load; unfortunately, the results have only limited usefulness because equipment is limited to 1-in. maximum particle sizes
2. The resilient modulus (M_R) of subgrade soils can be expressed as (Rada and Witczak, 1981):

$$M_R = A\theta^B$$

where:

θ = first invariant of stress (sum of the three principal stresses)
A & B = experimentally determined parameters

3. Tests for the parameters A and B can be conducted according to AASHTO T 274. The maximum tire shred size is limited to 1-in. by the testing apparatus which precludes the general applicability of this procedure to the larger size tire shreds typically used for civil engineering applications.
4. Ahmed (1993) applied AASHTO T 274-82 to tire shreds and tire shred/soil mixtures. Modulus values ranged from 100 to 245 psi. Two soil types were used: (1) Ottawa sand; and (2) Crosby Till. Their results are summarized in Table IV-4. The parameter A, and therefore M_R, decreases as the percent tire shreds by dry weight of the mix increases. Edil and Bosscher (1992, 1994) measured the resilient modulus of mixtures of tire shreds and sand. However, the tire shred size and details of the testing procedure were not given. Their results are summarized in Fig. IV-7. Shao, et al. (1995) performed resilient modulus tests on crumb rubber (1/4-in. maximum size) and rubber buffings (0.04-in. maximum size). The resilient modulus values ranged from 100 to 245 psi.

F. Time dependent settlement of tire shred fills

1. Time dependent settlement of thick tire shred fills was measured by Tweedie, et al. (1998a)
2. Three types of tire shreds were tested with maximum size ranging from 1.5 to 3-in.
3. The fill was 14-ft thick and was surcharged with 750 psf, which is equivalent to about 6 ft of soil

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4. Vertical strain versus elapsed time is shown in Fig. IV-8; it is seen that significant time dependent settlement occurs for about 2 months after the surcharge was placed; during the first two months about 2% vertical strain occurred which is equivalent to more than 3 in. of settlement

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Table IV-4. Resilient modulus of tire shreds and tire shred/soil mixtures (Ahmed, 1993).

Test no.	Tire shred max. size (in.)	Sample preparation	% tire shreds based on total weight	Soil type	Constant A	Constant B	r^2
AH01	No Shreds	Vibratory	No Shreds	Sand	1071.5	0.84	0.95
AH02	0.5	Vibratory	15	Sand	524.8	0.83	0.95
AH03	0.5	Vibratory	30	Sand	269.2	0.90	0.67
AH04	0.5	Vibratory	38	Sand	42.7	1.15	0.89
AH05	0.5	Vibratory	50	Sand	38.9	0.83	0.84
AH06	0.5	Vibratory	100	Sand	36.3	0.55	0.74
AH07	0.75	Vibratory	38	Sand	34.7	1.21	0.92
AH08	No Shreds	Standard	No Shreds	Crosby Till	3162.3	0.49	0.83
AH09	0.5	Standard	15	Crosby Till	53.7	1.15	0.91
AH10	0.5	Standard	29	Crosby Till	61.7	0.91	0.94
AH11	0.5	Standard	38	Crosby Till	55.0	0.67	0.95

Notes:
1. Constants A & B are the constants for the regression equation and r^2 is the regression coefficient
2. Standard = Standard Proctor Energy = 12,375 ft-lb/ft^3
3. The constants A and B assume the units for θ and M_R are psi.

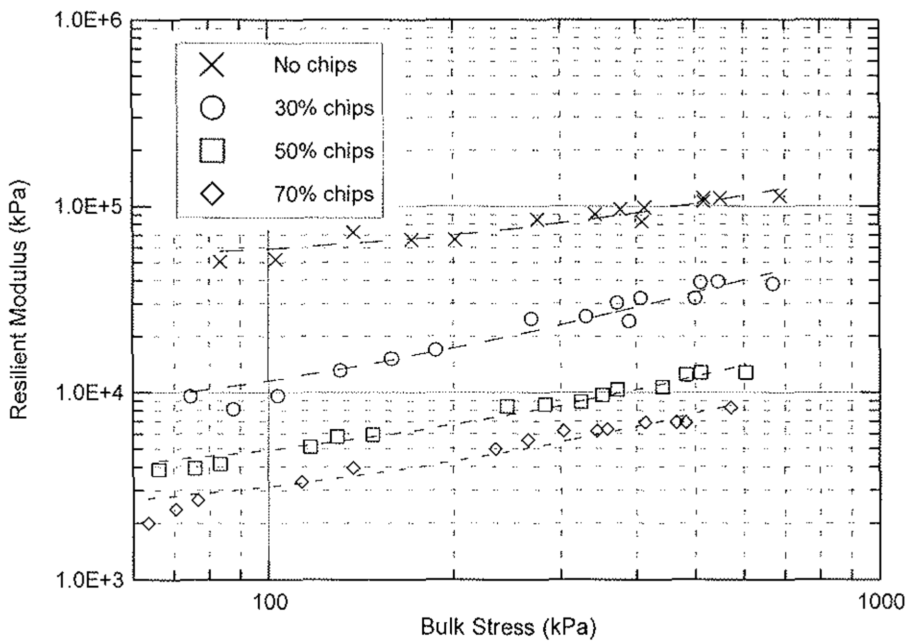

Fig. IV-7. Resilient modulus of mixtures of tire shreds and clean sand (Edil and Bosscher, 1992)

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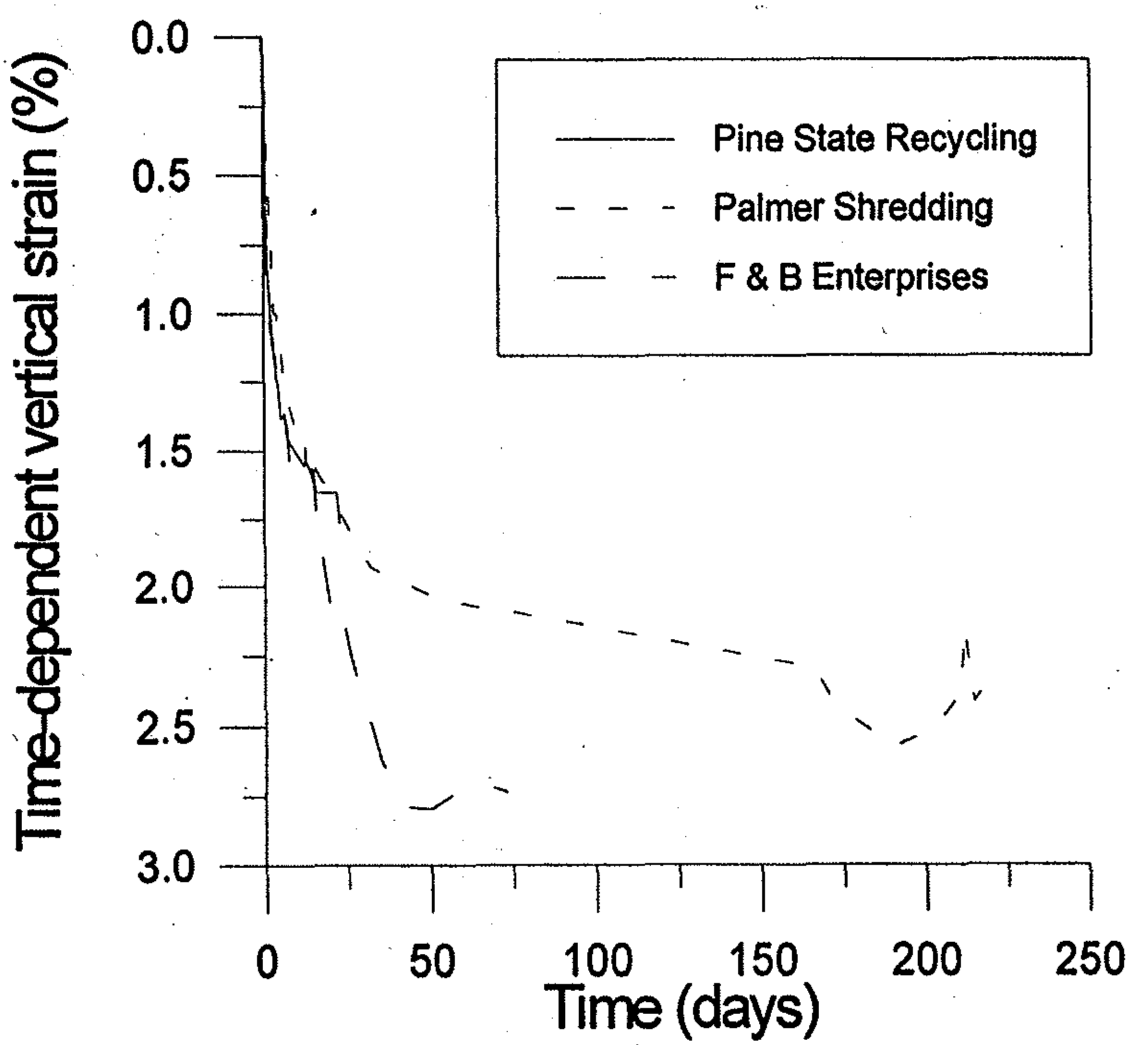

Fig. IV-8. Time dependent settlement of 14-ft thick tire shred fill with surcharge of 750 psf (Tweedie, et al., 1998a)

G. Lateral earth pressure

1. The lateral earth pressure of tire shreds is important for design of earth retaining structures; it is characterized by the coefficient of lateral earth pressure at rest K_o which is the ratio of the horizontal stress divided by the vertical stress; a related parameter is Poisson's ratio μ which relates horizontal deformation to vertical deformation

2. The coefficient of lateral earth pressure at rest K_o and Poisson's ratio μ have been determined from the results of confined compression tests where the horizontal stresses were measured. K_o and μ are calculated from:

$$K_o = \sigma_h/\sigma_v$$

$$\mu = K_o/(1 + K_o)$$

where:

σ_h = measured horizontal stress, and

σ_v = measured vertical stress.

3. Values of K_o and μ reported by several investigators are summarized in Table IV-5. Reported values of K_o ranged from 0.47 to 0.26. Values of μ ranged from 0.17 to 0.32.

Table IV-5. Summary of coefficient of lateral earth pressure at rest and Poisson's ratio.

Particle size range (in.)	Tire shred type	Source of tire shreds	K_o	μ	Reference
2	Mixed	Sawyer Environmental	0.44	0.30	(1)
3	Mixed	Palmer Shredding	0.26	0.20	(2)
2	Mixed	Pine State Recycling	0.41	0.28	(2)
1	Glass	F & B Enterprises	0.47	0.32	(2)
----	----	----	----	0.3 to 0.17	(3)
2	Mixed	Maust Tire Recycles	0.4[a]	0.3	(4)

Notes: a. For vertical stress less than 25 psi.

References: (1) Manion and Humphrey (1992); Humphrey and Manion (1992)
(2) Humphrey, et al. (1992, 1993); Humphrey and Sandford (1993)
(3) Edil and Bosscher (1992, 1994)
(4) Drescher and Newcomb (1994)

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H. Shear strength

1. The shear strength of tire shreds may be determined in a direct shear apparatus in accordance with ASTM D 3080 or using a triaxial shear apparatus.

    a) The large size of tire shreds typically used for civil engineering applications requires that specimen sizes be several times greater than used for common soils. Because of the limited availability of large triaxial shear apparatus this method has generally been used for tire chips 1-in. in size and smaller.

    b) Extrapolation of results on small size shreds to the 3-in. and larger size shreds used for civil engineering applications is uncertain since small shreds are nearly equidimensional while larger shreds tend to be long and flat.

    c) The triaxial shear apparatus is generally not suitable for tire shreds that have steel belts protruding from the cut edges of the shreds since the wires would puncture the membrane used to surround the specimen.

2. The shear strength of tire shreds has been measured using triaxial shear by Bressette (1984), Ahmed (1993), and Benda (1995); and using direct shear by Humphrey, et al. (1992, 1993), Humphrey and Sandford (1993), and Cosgrove (1995). Results from a direct shear test are show in Fig. IV-9.

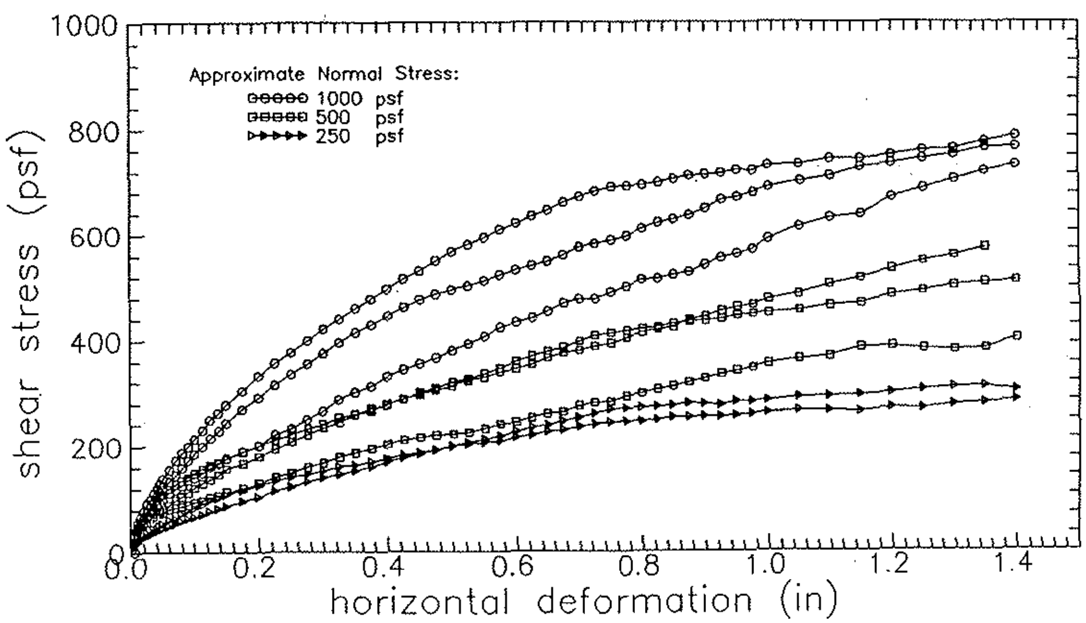

Fig. IV-9. Shear stress vs. horizontal deformation for Pine State Recycling tire shreds tested in direct shear box (Humphrey, et al., 1992)

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3. Failure envelopes for tests conducted at low stress levels (less than about 2000 psf) are compared in Fig. IV-10. The failure envelopes are non-liner and concave down, so when fitting a linear failure envelope to the data, it is important that this be done over the range of stresses that will occur in the field.
4. Ahmed (1993) conducted tests at higher stress levels (greater than 1500 psf) on tire shreds with a maximum size of 0.5 in. and 1 in. The failure envelopes were approximately linear. Using a failure criteria of 15 % axial strain, cohesion intercepts from 572 to 689 psf and friction angles from 15.9 to 20.3 degrees were obtained.
5. Bressette (1984) tested two samples. One was termed "2-in. square" and it had a cohesion intercept of 540 psf and a friction angle of 21°. The other was termed "2-in. shredded" and it had a cohesion intercept of 910 psf and a friction angle of 14°. No other information on the tests was given.
6. The shear strength of tire shred/soil mixtures has been measured using triaxial shear by Hannon and Forsyth (1973) and Ahmed (1993), and using direct shear by Edil and Bosscher (1992), and Benson and Khire (1995). Tables IV-6 and IV-7 summarize the results from Ahmed (1993). Edil and Bosscher (1992), and Benson and Khire (1995) were primarily interested in the reinforcing effect of tire shreds when added to a sand. Under some circumstances, the shear strength was increased by adding tire shreds.
7. The interface strength between tire shreds and geomembrane was measured in a large scale direct shear test by Cosgrove (1995); this information is needed when tire shreds in some landfill applications.

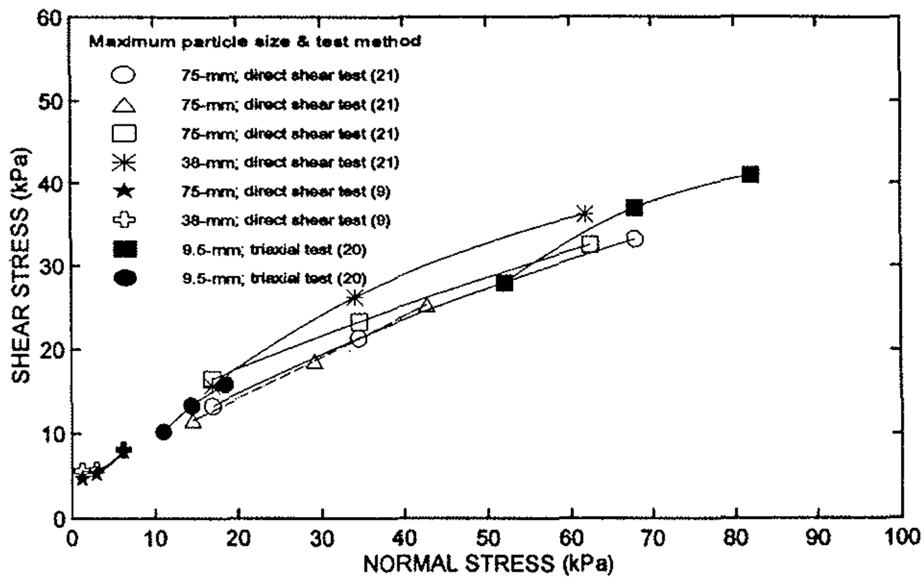

Fig. IV-10. Comparison of failure envelopes of tire shreds at low stress levels (21. Humphrey, et al, 1992; 9. Cosgrove, 1995; 20. Benda, 1995).

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Table IV-6. Shear strength of mixtures of tire chips and Ottawa sand (Ahmed, 1993)

Test No.	Size of Chips (in.)	Chip/mix ratio (%)	Confining Pressure (psi)	Strain Levels (%)	a (psi)	tan α	r^2	c (psi)	ϕ (°)
TRS01	No-Chip	0	4.50	5	−0.24	0.6615	0.9998	0	41.41
TRS02	No-Chip	0	14.36	10	-	-	-	-	-
TRS03	No-Chip	0	28.86	15	-	-	-	-	-
TRS04	1.00	16.5	4.64	5	2.17	0.6006	0.9996	2.71	36.91
TRS05	1.00	16.5	14.50	10	1.05	0.6252	0.9998	1.35	38.70
TRS06	1.00	16.5	28.86	15	-	-	-	-	-
TRS07	1.00	29.16	4.50	5	5.52	0.4944	0.9943	6.35	29.63
TRS08	1.00	29.16	14.50	10	3.04	0.6110	0.9992	3.84	37.66
TRS09	1.00	29.16	28.86	15	2.65	0.6286	0.9993	3.41	38.95
TRS10	1.00	40.00	4.64	5	5.15	0.3957	0.9988	5.61	23.31
TRS11	1.00	40.00	14.36	10	5.13	0.5413	0.9972	6.10	32.77
TRS12	1.00	40.00	28.86	15	4.09	0.6013	0.9999	5.12	36.96
TRS13	1.00	50.00	4.64	5	−0.68	0.3562	0.9601	0.00	20.87
TRS14	1.00	50.00	14.36	10	4.54	0.4362	0.9988	5.05	25.86
TRS15	1.00	50.00	28.71	15	3.84	0.5519	0.9986	4.60	33.50
TRS16	1.00	66.54	4.50	5	2.23	0.1699	0.9999	2.26	9.78
TRS17	1.00	66.54	14.36	10	1.89	0.3324	0.9901	2.00	19.41
TRS18	1.00	66.54	28.71	15	4.91	0.3759	0.9992	5.30	22.08
TRS19	0.50	37.85	4.64	5	5.26	0.3891	0.9998	5.71	22.90
TRS20	0.50	37.85	14.50	10	5.48	0.5383	1.0000	6.50	32.57
TRS21	0.50	37.85	28.71	15	4.42	0.6238	0.9998	5.66	38.59
TRS22	1.00	38.78	4.64	5	6.55	0.4299	0.9964	7.25	25.46
TRS23	1.00	39.32	14.36	10	5.17	0.5684	0.9985	6.28	34.64
TRS24	1.00	39.37	28.71	15	4.08	0.617	0.9999	5.18	38.10

Notes:
1. All samples are prepared by using vibratory compaction
2. Chip ratio is the air dried weight of chips divided by dry weight of mix, expressed in percent

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Table IV-7. Shear strength of mixtures of tire chips and Crosby till (Ahmed, 1993)

Test No.	Size of Chips (in.)	Chip ratio (%)	Confining Pressure (psi)	Strain Levels (%)	a (psi)	tan α	r^2	c (psi)	φ (°)
TRC01	No-Chip	0	4.50	5	6.14	0.4299	0.9970	6.80	25.46
TRC02	No-Chip	0	14.50	10	9.28	0.4914	1.0000	10.66	29.43
TRC03	No-Chip	0	28.71	15	9.72	0.5099	0.9996	11.30	30.66
				20	9.58	0.5151	0.9996	11.18	30.00
TRC04	1.00	16.27	4.64	5	7.43	0.3873	0.9979	8.06	22.79
TRC05	1.00	16.27	14.36	10	6.21	0.5810	0.9982	7.63	35.52
TRC06	1.00	16.27	28.71	15	7.77	0.5686	0.9992	9.45	34.65
				20	5.71	0.6232	0.9992	7.30	38.55
TRC07	1.00	30.18	44.52	5	6.82	0.2612	0.9991	7.67	15.14
TRC08	1.00	30.18	14.36	10	9.96	0.3740	0.9997	10.74	21.96
TRC09	1.00	30.18	28.86	15	9.88	0.4748	0.9973	11.23	28.35
				20	8.82	0.5460	0.9971	10.53	33.09
TRC10	1.00	40.05	4.64	5	5.50	0.2205	0.9947	5.64	12.74
TRC11	1.00	40.05	14.36	10	7.65	0.3598	0.9990	8.20	21.09
TRC12	1.00	40.05	28.71	15	8.39	0.4543	0.9991	9.42	27.02
				20	8.44	0.5271	0.9999	9.93	31.81
TRC13	1.00	48.49	4.64	5	4.93	0.2025	0.9985	5.03	11.68
TRC14	1.00	48.49	14.36	10	6.69	0.3472	0.9999	7.13	20.32
TRC15	1.00	48.49	28.86	15	7.81	0.4441	0.9999	8.72	26.37
				20	7.92	0.5208	0.9999	9.28	31.39
TRC16	0.50	39.80	4.64	5	6.17	0.1173	0.9980	6.21	6.74
TRC17	0.50	39.80	14.36	10	9.37	0.2181	0.9875	9.60	12.60
TRC18	0.50	39.80	28.86	15	11.07	0.3130	0.9866	11.66	18.24
TRC19	0.50	39.64	14.36						
TRC20	0.50	39.79	14.36						

Notes: 1. Chip ratio is the air dried weight of chips divided by dry weight of mix, expressed in percent

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I. Hydraulic conductivity (permeability)

1. The hydraulic conductivity of tire shreds is much greater than most granular soils

2. The hydraulic conductivity (permeability) of tire chips smaller than 3/4-in. in size can be determined in accordance with Test Method D 2434. However, tire shreds and tire shred/soil mixtures used for civil engineering applications almost always have a majority of their particles larger than 3/4-in., so this method is generally not applicable - have to use a larger permeameter

3. The hydraulic conductivity of tire shreds and tire shred/soil mixtures has been measured with constant head permeameters ranging in diameter from 203 mm to 305 mm (Bressette, 1984; Hall, 1990; Humphrey, et al., 1992, 1993; Humphrey and Sandford, 1993; Edil and Bosscher, 1992, 1994; Ahmed, 1993; Ahmed and Lovell, 1993). Some permeameters had provisions to apply a vertical stress to the sample to simulate the compression that would occur under the weight of overlying soil cover. The high hydraulic conductivity of tire shreds precludes the applicability of available test methods.

4. The hydraulic conductivity of tire shreds determined in several investigations is summarized in Table IV-8. Hydraulic conductivities from 0.58 cm/s to 23.5 cm/s were reported. Results from Edil and Bosscher (1992, 1994) are not included in Table IV-8 because they noted that the limited flow capacity of their permeameter casts doubt on the reliability of their reported hydraulic conductivities.

5. The hydraulic conductivities of tire shred/soil mixtures have been measured by Edil and Bosscher (1992, 1994), and Ahmed (1993). Edil and Bosscher (1992, 1994) used mixtures of tire shreds with a 3-in. maximum size and a clean uniform sand. Surcharge pressures between 0 and 2,880 psf were applied to the samples. Their results are summarized in Fig. IV-11. The hydraulic conductivity for samples with 0% sand (100% tire shreds) is probably higher than reported because their permeameter had inadequate flow capacity (i.e., for samples with 100% tire shreds, they were measuring the hydraulic conductivity of the permeameter). Ahmed (1993) used mixtures of tire shreds with 0.5 or 1-in. maximum size and two soil types: (1) uniformly graded Ottawa sand; and (2) a fine grained glacial till (Crosby Till). No surcharge pressure was applied to the samples. The results are summarized in Table IV-9. Lawrence, et al. (1998) measured the hydraulic conductivities of mixtures of tire shreds and granular soil. Their results are summarized in Figure IV-10. For all three studies, the hydraulic conductivity decreases significantly as the percent soil in the mix increases.

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Table IV-8. Summary of reported hydraulic conductivities of tire shreds.

Particle size (in.)	Void ratio	Dry density (pcf)	Hydraulic conductivity (cm/sec)	Reference
2.5		29.0	5.3 to 23.5	Bressette (1984)
2.5		37.9	2.9 to 10.9	
2		29.3	4.9 to 59.3	
2		38.1	3.8 to 22.0	
1.5	----	----	1.4 to 2.6	Hall (1990)
0.75	----	----	0.8 to 2.6	
2	0.925	40.2	7.7	Humphrey, et al. (1992, 1993)
2	0.488	52.0	2.1	
3	1.114	37.5	15.4	
3	0.583	50.1	4.8	
1.5	0.833	38.8	6.9	
1.5	0.414	50.4	1.5	
1.5		0.653	0.58	Ahmed (1993)
1.5	0.693	42.0	7.6	Lawrence, et al. (1998)
1.5	0.328	53.6	1.5	
3	0.857	41.7	16.3	
3	0.546	50.1	5.6	

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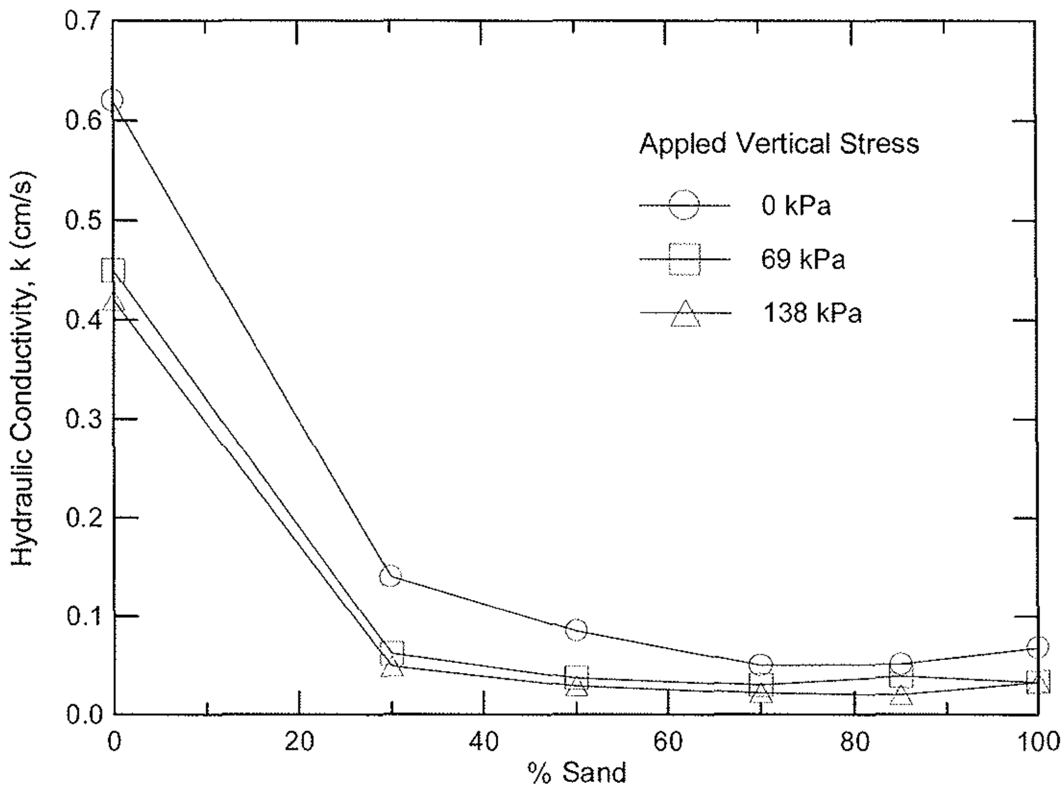

Fig. IV-9. Hydraulic conductivities of mixtures of tire shreds and clean sand (Edil and Bosscher, 1992)

Table IV-9. Hydraulic conductivities of mixtures of tire chips and soil (Ahmed, 1993).

Tire chip maximum size (in.)	Soil type	% tire chips based on total weight	Dry unit weight (pcf)	Hydraulic conductivity (cm/s)
-----	Ottawa sand	0	118	1.6×10^{-4}
1	Ottawa sand	15.5	105	1.8×10^{-3}
1	Ottawa sand	30.1	95.5	3.5×10^{-3}
1	Ottawa sand	37.7	88.0	8.7×10^{-3}
-----	Crosby till	0	119	8.9×10^{-7}
1	Crosby till	14.8	106	1.8×10^{-5}
1	Crosby till	30.1	86.7	2.1×10^{-3}
1	Crosby till	40	74.9	8.8×10^{-3}
0.5	Crosby till	40	74.3	9.7×10^{-3}

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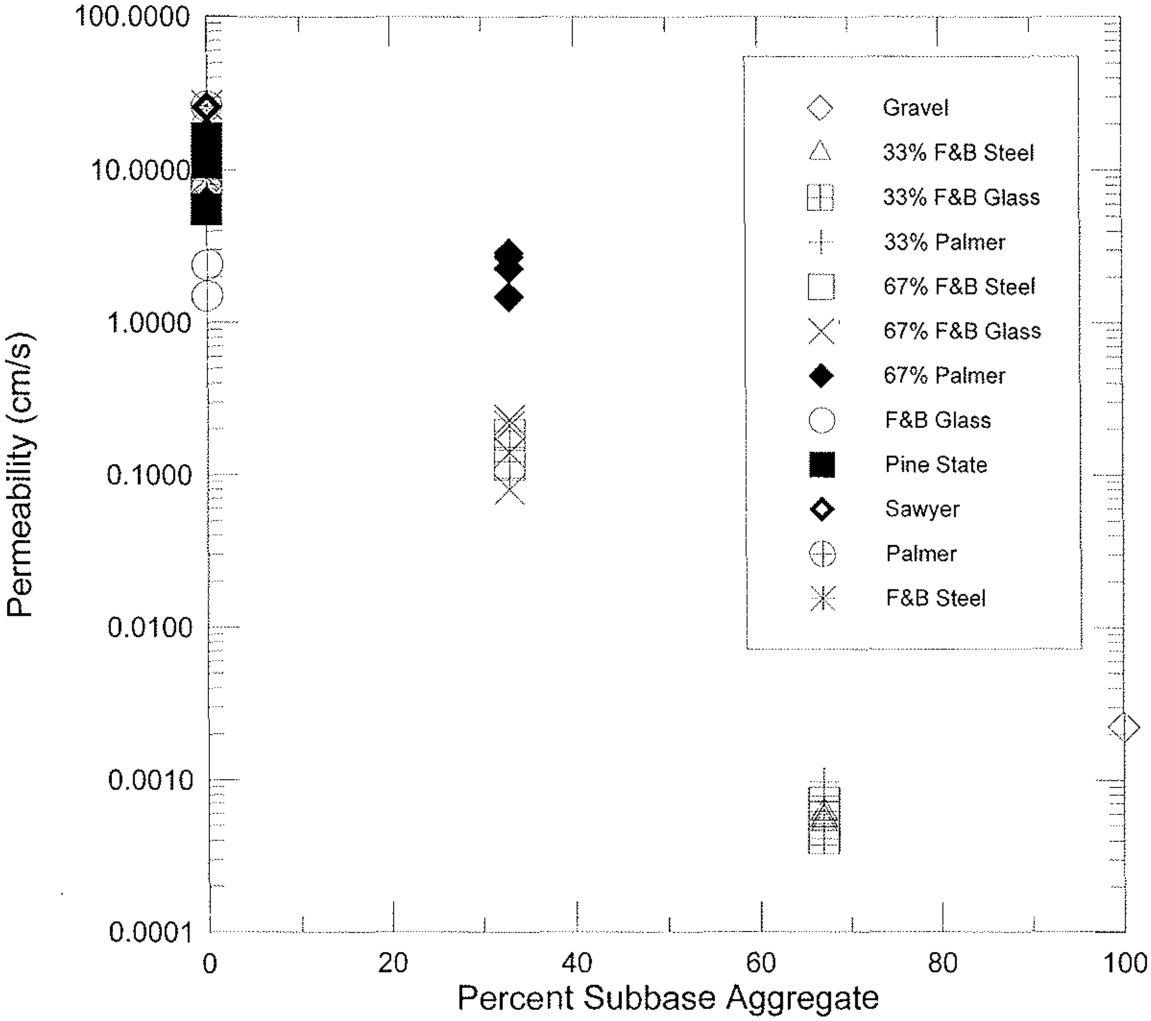

Fig. IV-10. Hydraulic conductivities of tire shred soil mixtures measured by Lawrence, et al. (1998).

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J. Thermal conductivity

1. The thermal conductivity of tire shreds is significantly lower than for common soils.

2. Shao, et al. (1995) used a guarded hot plate apparatus to test samples with maximum particle sizes ranging from 0.04 to 1 in. The larger sizes contained the remains of steel belts. Measured thermal conductivities ranged from 0.0563 Btu/hr-ft-°F (0.0838 Cal/m-hr-°C) for 0.04 in. particles (rubber buffings) tested in a thawed state with a water content less than 1% and with low compaction to 0.0988 Btu/hr-ft-°F (0.147 Cal/m-hr-°C) for 1 in. tire shreds tested in a frozen state with a water content of 5% and high compaction. The thermal conductivity increased with increasing particle size, increased water content, and increased compaction. The thermal conductivity was higher for tire shreds tested under frozen conditions than when tested under thawed conditions.

3. Humphrey, Chen, and Eaton (1997) back calculated a thermal conductivity of 0.12 Btu/hr-ft-°F (0.20 W/m·°C) from a field trial constructed using tire shreds with a maximum size of 2 in. (Humphrey and Eaton, 1993a, 1993b, 1994, 1995). It is reasonable that the back calculated thermal conductivity is higher than found by Shao, et al. (1994) since the tire shreds for the former were larger and contained more steel bead wire and steel belt.

4. For comparison the thermal conductivity of typical soils are about 1 Btu/hr-ft-°F

5. The laboratory measured "apparent thermal conductivity" of five types of tire shreds (maximum size ranging from 1.5 in. to 3 in.) are summarized in Table IV-10 (apparent thermal conductivity includes the effects of nonconductive modes of heat transfer, namely radiation and free convection of air within the voids; these modes of heat transfer will occur under field conditions when tire shreds are used as insulation; thus, the apparent thermal conductivity is the value that should be used for field design)

6. The thermal conductivity tends to increase as the density increases as shown in Fig. IV-11

7. Thermal conductivity probably increases as the shred size increases, since larger size shreds would allow more air to circulate in the voids, thus tire shreds used of insulation should have a maximum size of 3-in.

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Table IV-10 Summary of apparent thermal conductivities of air dried tire shreds (Lawrence, et al., 1998)

Sample	Density		Void Ratio	Apparent thermal conductivity		Surcharge
	(pcf)	(Mg/m^3)		(Btu/hr·ft·°F)	(W/m·°C)	
gravel	117.6	1.88	0.41	0.295	0.510	none
	121.6	1.95	0.36	0.326	0.563	half
	123.0	1.97	0.34	0.345	0.596	full
F&B-g	38.5	0.62	0.85	0.120	0.207	none
	43.3	0.69	0.64	0.113	0.195	half
	45.4	0.73	0.56	0.114	0.197	full
F&B-s	39.1	0.63	0.85	0.145	0.251	none
	42.8	0.69	0.69	0.130	0.225	half
	45.3	0.73	0.60	0.134	0.232	full
Palmer	39.7	0.64	0.998	0.159	0.275	none
	45.1	0.72	0.76	0.119	0.206	half
	48.5	0.78	0.63	0.125	0.216	full
Pine State	39.2	0.63	0.97	0.158	0.273	none
	45.4	0.73	0.7	0.139	0.240	half
	49.6	0.79	0.56	0.114	0.197	full
Sawyer	36.0	0.58	1.13	0.184	0.318	none
	41.0	0.66	0.87	0.148	0.256	half
	43.7	0.70	0.76	0.156	0.270	full

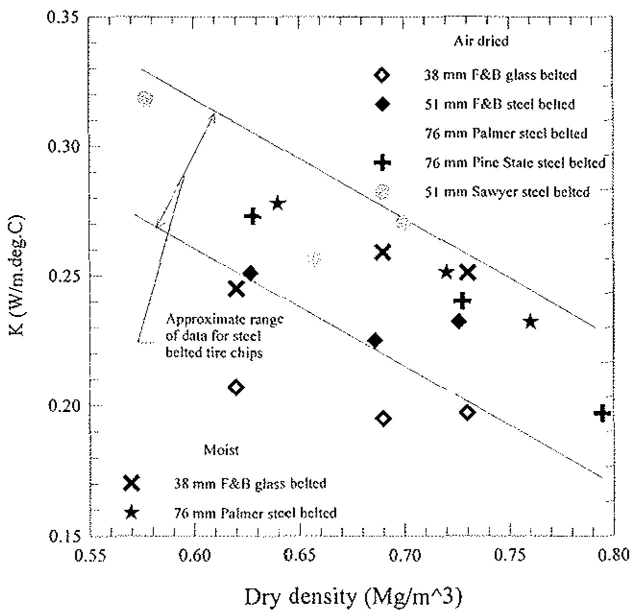

Fig. IV-11. Apparent thermal conductivity of tire shreds vs. density (Lawrence, et al., 1998).

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V. LIGHTWEIGHT AND CONVENTIONAL FILL BENEATH ROADS

A. Case history - Roseburg, Oregon

1. Located on U.S. Route 42 near Roseburg, Oregon (Upton and Machan, 1993)
2. As part of a highway improvement project an embankment was raised and widened; this reactivated an old landslide
3. Stabilized the slide by a combination of shredded tires as lightweight fill to reduce the driving force at the head of the slide and by placing a counterbalancing fill at the toe of the slide as shown in Figs. V-1 and V-2
4. Construction occurred in 1990; final paving was done in 1991
5. Specifications were the same as had been used previously by the Minnesota DOT; they called for tire shreds with 80% passing the 8-in. size and 50% larger than the 4-in. size; the maximum size measured in any direction was 24 in.; specification for metal fragments was as follows: "All metal fragments shall be firmly attached and 98% embedded in the tire sections from which they are cut. NO METAL PARTICLES SHALL BE PLACED IN THE FILL WITHOUT BEING CONTAINED WITHIN A RUBBER SEGMENT. Ends of metal belts and beads are expected to be exposed only in the cut faces of some tire shreds." -- they note that the tire shred fill contained oversize pieces and excess metal fragments
6. Tire shreds were placed in 3-ft lifts and compacted with three passes of a D-8 bulldozer; also tried a D-6 but it appeared to be less effective than the D-8; side slopes were trimmed with an excavator; tire shreds separated from the surrounding soil with a geotextile; maximum thickness of tire shred fill was about 14 ft; at one point exposed an 8-ft high vertical face of tire shreds
7. After compaction, but before placement of the overlying soil cover, the tire shred unit weight was estimated to be 45 pcf
8. The overlying cover consisted of 36 in. of soil, 23 in. of aggregate base course; total soil cover was 59 in. (almost 5 ft); 8-in. pavement thickness
9. After compression under weight of overlying material, unit weight was estimated to be 53 pcf
10. In one 50-ft long section, the soil cover was inadvertently 1 to 1.5-ft thinner than specified; pavement cracking and rutting was observed in this section which had to be repaired; performance in other sections was satisfactory
11. Pavement deflections were measured with a falling weight deflectometer; deflections were about 0.25 mm which corresponds to the maximum deflection allowed by the Oregon DOT for a 20 yr design life; results are summarized in Fig. V-3

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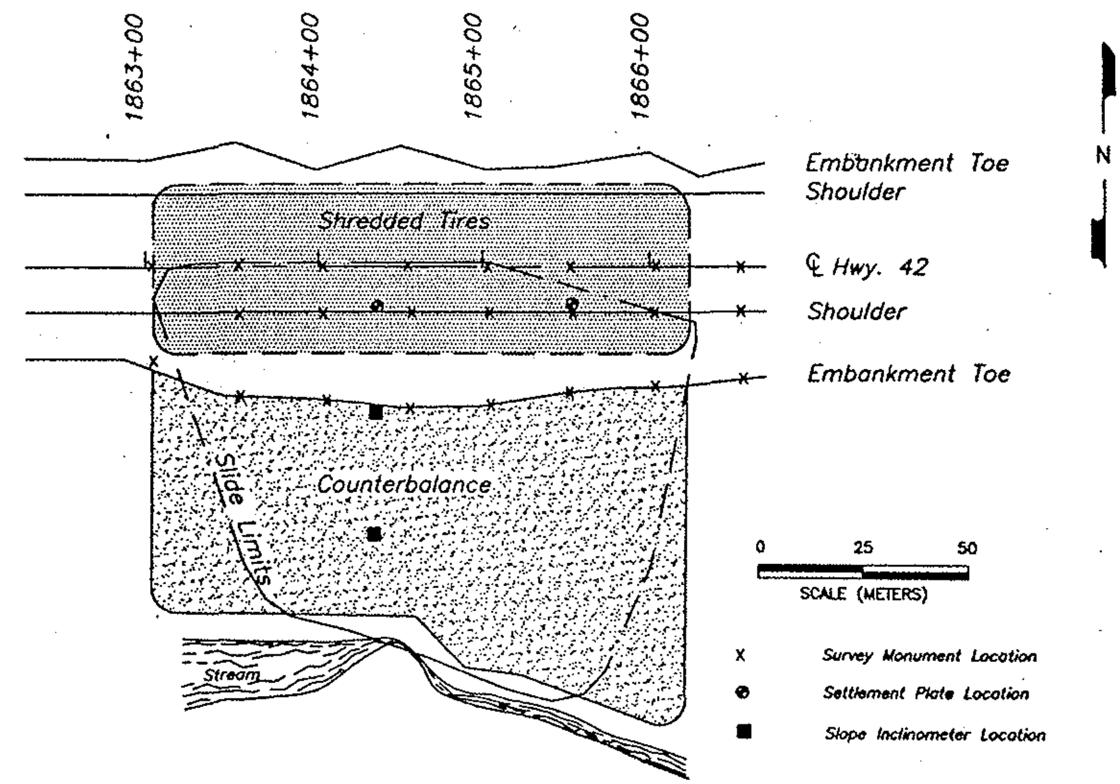

Fig. V-1. Plan view of Oregon tire shred field trial (Upton and Machan, 1993)

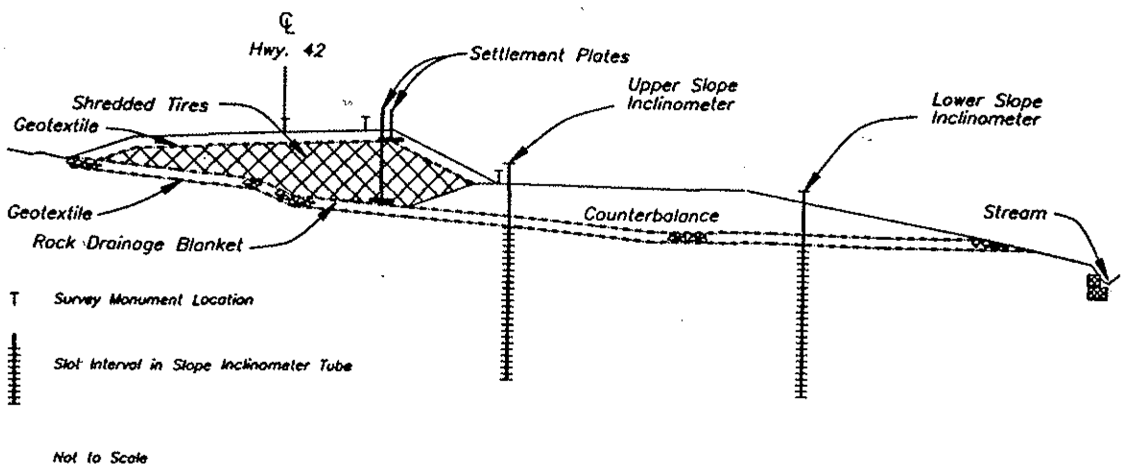

Fig. V-2. Cross section through Oregon tire shreds field trail (Upton and Machan, 1993)

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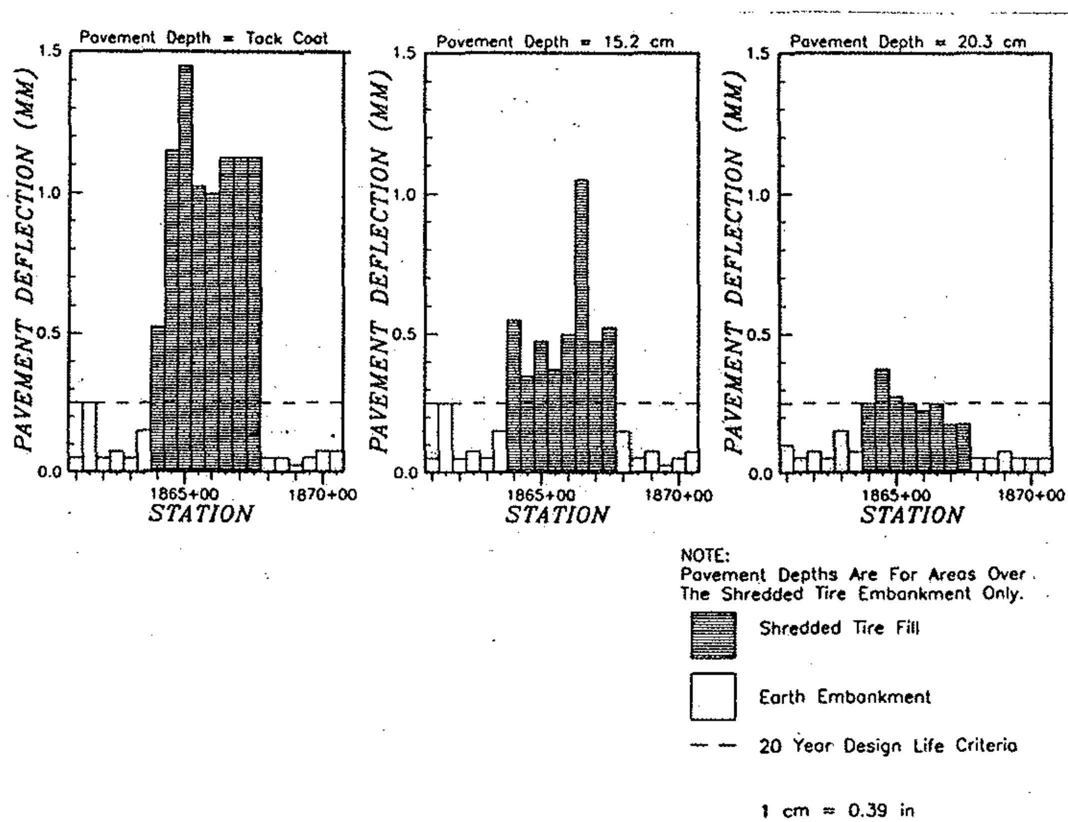

Fig. V-3. Deflectometer test data: *left*, October 30, 1990; *middle*, January 7, 1991; *right*, December 12, 1991 (Upton and Machan, 1993)

12. Cost of the tire shreds delivered to the site was $30/ton with placement costing an additional $8.33/ton; the total cost on based on c.y. was $27/c.y.; on this job, a state subsidy reduced the cost to ODOT to $13/c.y.

B. Case history - Double Nickel Slide, South Pass, Wyoming

1. References: Dagil, 1994; personal communication, Michael Hager, WDOT, 1995; personal communication, Jan Winsborough, The Tire Recyclers, 1995

2. Located on State Highway 28 about 20 miles south of Lander

3. A highway realignment in 1985 initiated a landslide; first signs of the slide noted in 1987; 1.5 to 2 ft of vertical displacement of roadway; the base of the sliding surface was at a depth of 80 ft the initial slide was stabilized with rock drains and berms installed at the toe of the slide

4. By 1993 additional movement was noted at NE end of slide area; failure surface at depth of 50 ft; plan and cross sectional views of slide area are shown in Figs. V-4 and V-5

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5. Possible repair options were

   a) Shift alignment to move away from head of slide

   b) Lowering grade to reduce driving force

   c) Lightweight fill

      (1) Wood shreds - 35 pcf; $8-15/c.y.

      (2) Shredded tires - 35 pcf; $4/c.y.

      (3) GeoFoam - 1.5 pcf; $30-50/c.y.

   d) Additional toe berms

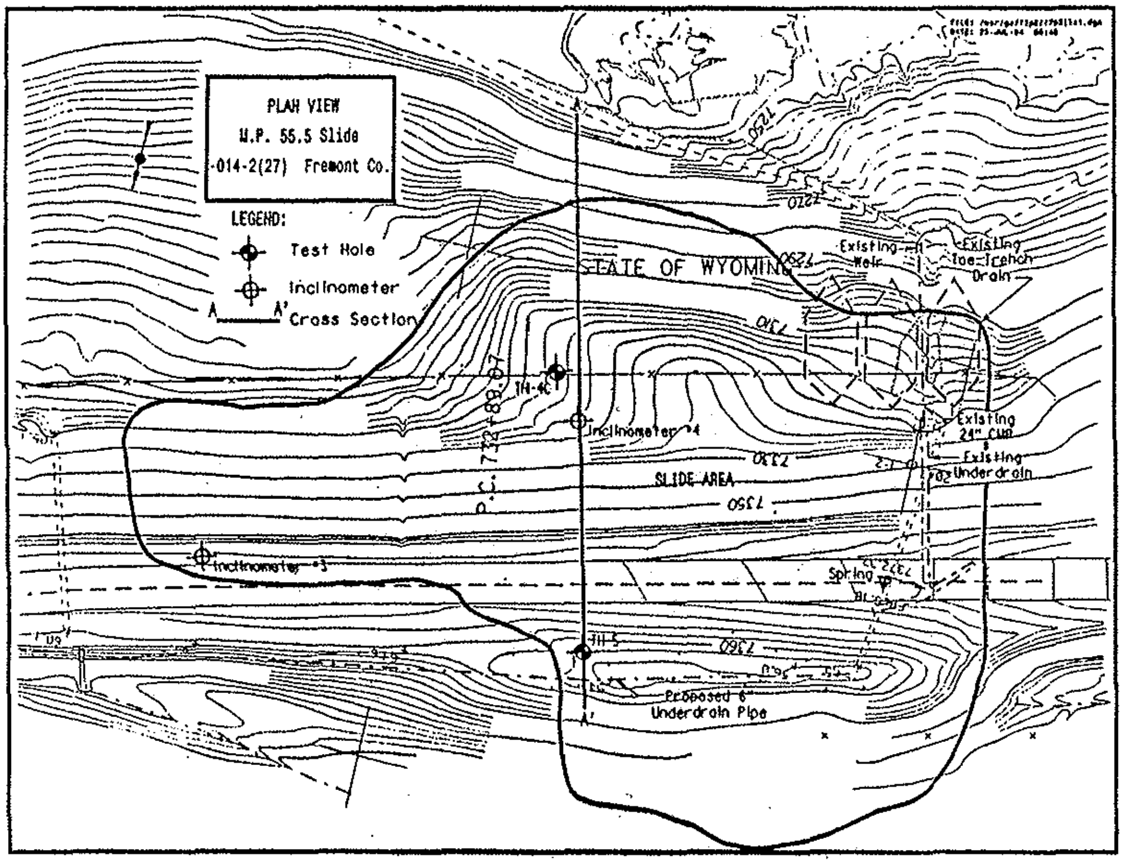

Fig. V-4. Plan view showing outline of slide area (Dahill, 1994)

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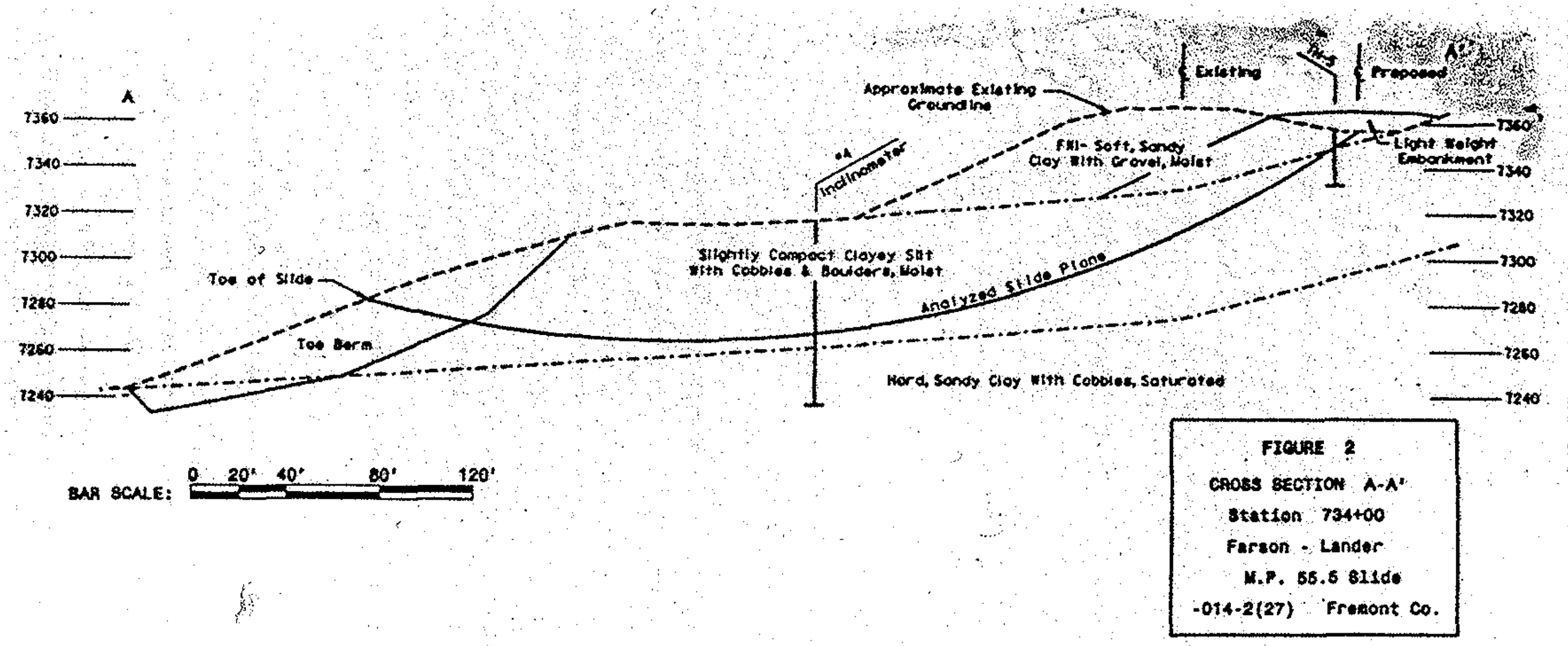

Fig. V-5. Cross section through slide area with slide plane used for analysis (Dahill, 1994)

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5. Used combination of the four options with shredded tires chosen as the lightweight fill as shown on cross section V-5
6. Construction plans indicate that the tire shred layer was 6± ft thick although thickness may have been altered during construction; tire shreds were rough shreds placed in 1-ft thick lifts and compacted with five passes of a bulldozer; geotextile was used to separate the tire shreds from the soil
7. Tire shreds covered by 36 in. of pit run subbase aggregate, 12 in. of crushed base aggregate, and 6 in. of pavement as shown in Fig. V-6
8. The final quantities of tire shreds used were 10,032 c.y. in-place; this translates into an estimated 470,000 to 630,000 tires

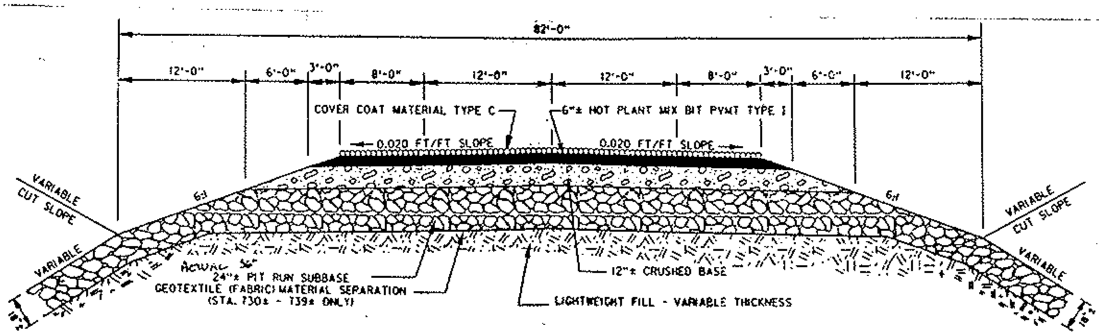

Fig. V-6. Typical section through pavement and base and subbase courses at the Double Nickel Slide.

C. Case history – Portland Jetport

1. New connector roadway with bridge over Maine Turnpike to provide improved access to Portland (Maine) Jetport and Congress Street (Humphrey, et. al., 1998)

2. Approach embankments up to 32 ft high founded on 39 ft of soft marine clay – factor of safety against slope failure unacceptably low

3. To increase factors of safety, the geotechnical designers for the project, Haley & Aldrich of South Portland, considered: 1) stabilizing berms; 2) ground improvement such as stone columns and deep soil mixing; and 3) lightweight fill were considered. Stabilizing berms were eliminated due to their impact on adjacent wetlands. Lightweight fill was selected as the best remaining alternative based on lower construction cost and tire shreds

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proved to be the lowest cost lightweight fill – use of tire shreds save $300,000 over the next cheapest alternative

4. Up to 20 ft of tire shreds were needed to meet stability requirements, however, guidelines to limit embankment heating recommend layer thicknesses no greater than 10 ft. Thus, the tire shreds were separated into two layers separated by 3 ft of low permeability soil as show in Fig. V-7.

5. Shreds were produced off-site at an abandoned tire stockpile in Durham, Maine. An estimated 1.2 million tires were used for this project. The average in-place density was about 49 pcf which is lower than expected during design. This may have been due to the large size, uniformly graded tire shreds.

6. Settlement data for the tire shred layers indicates rapid compression during loading with very little time-dependent movement. Settlement of the upper shred layer after approximately 5 months at full load varies from 5 to 21 in. (125 to 530 mm). Settlement of the lower shred layer varies from 5 to 18 in. (125 to 460 mm). Much of this settlement was due to the foundation which settled 2 to 15 in. (50 to 380 mm) during this period.

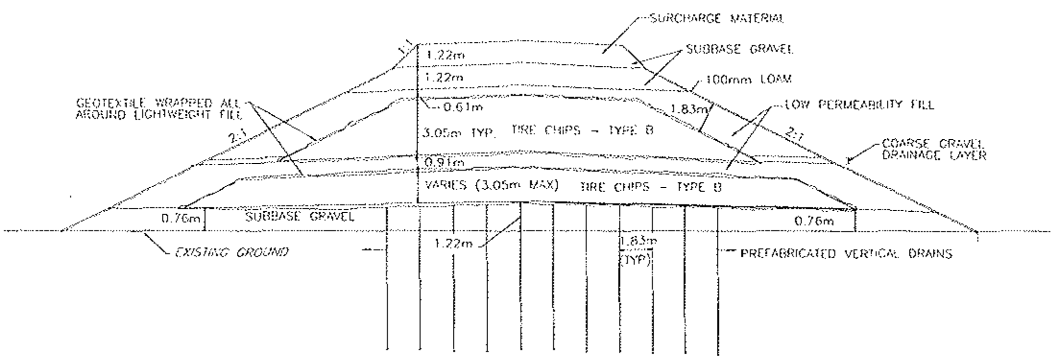

Fig. V-7. Typical embankment section, Portland Jetport.

D. Case history – Dixon Landing, California

1. The project is located in Milpitas, California at the intersection of I-880 and Dixon Landing Road. The site is underlain by about 30 ft of San Francisco Bay Mud, so lightweight fill was specified for most fill sections to reduce total settlement. The project owner is the California Department of Transportation (Caltrans).

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2. Two sources of lightweight fill were considered: tire shreds with an in-place unit weight of 50 pcf and lightweight aggregate with a unit weight of 70 pcf. Tire shreds were chosen for the onramp that will carry traffic from Dixon Landing Road to the southbound lane of I-880. They were chosen because they had a lower unit weight than the lightweight aggregate and because they were expected to be less expensive.

4. Tire shreds were supplied through an interagency agreement between the California Integrated Waste Management Board (CIWBM) and the California Department of Transportation (Caltrans). The CIWMB was responsible for procuring the tire shreds and having them delivered to the site. Tire shreds were required to be delivered at a minimum rate of 300 tons/day. Some of the tire shreds were delivered in advance and stockpiled at a nearby landfill to facilitate delivery in this traffic congested area. In total, 6627 tons or 662,700 passenger tire equivalents (PTE) of tire shreds were used for this project

5. Project design

   a. The tire shreds were placed in two layers, each up to 10 ft thick to meet the guidelines to limit heating of embankment heating. The layers were separated by 3 ft of low permeability soil. A typical embankment cross section is shown in Fig. V-8 and a longitudinal section is shown in Fig. V-9.

   b. At station 103+90 the embankment applied a vertical stress of 2250 psf to the foundation soil compared to 3750 psf for an embankment constructed with conventional earth fill. This is a 40% reduction in vertical stress.

   c. Conventional lightweight fill was used beneath the bridge abutment as shown in Fig. V-9. This would allow the piles for the bridge abutment to be driven through the volcanic pumice rather than tire shreds. Moreover, the dynamic properties of the tire shreds are not fully understood so there were concerns with tire shreds being required to support the bridge abutment during an earthquake.

6. Tire shreds were placed with conventional construction equipment. The construction process is shown in Figs. V-10 through V-17.

7. Unit cost comparison
   - Cost for common borrow = $7.48/yd^3$
   - Placement costs of shreds (including geotextile) = $3.74/yd^3$
   - Purchase & delivery costs of shreds (paid by CIWMB) = $23.66/yd^3$
   - In-place cost for shreds = $27.40/yd^3$
   - In-place cost for lightweight aggregate = $50.00/yd^3$

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7. Cost savings – the cost savings to Caltrans was $477,000 compared to using lightweight aggregate for the project. When the purchase price of the tire shreds is subtracted, the cost savings is still $230,000. This shows that tire shreds can be a cost effective alternative to lightweight aggregate.

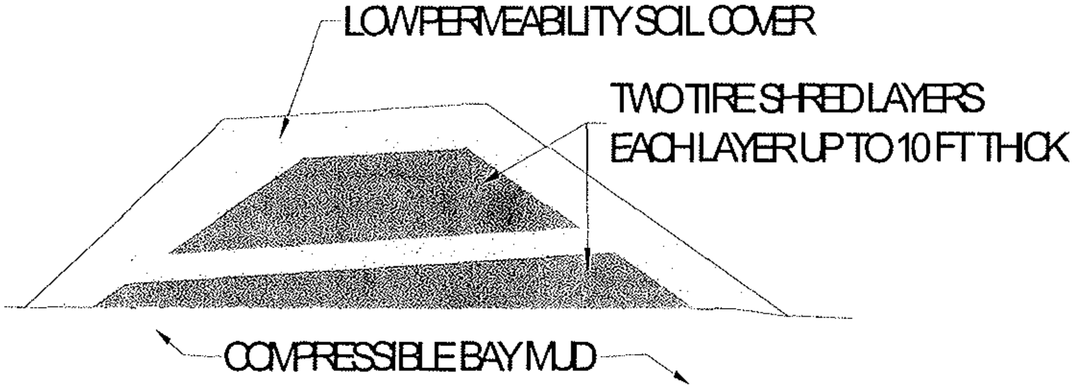

Fig. V-8. Typical cross section, Dixon Landing Interchange.

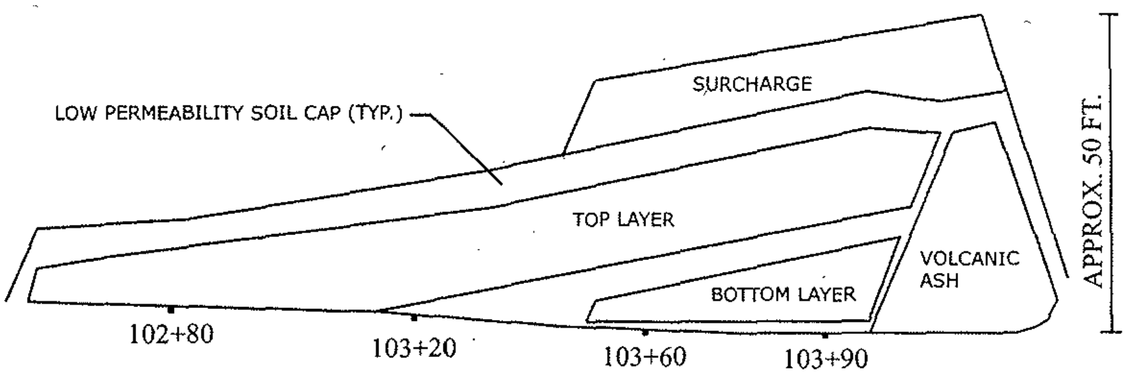

Fig. V-9. Longitudinal section, Dixon Landing Interchange.

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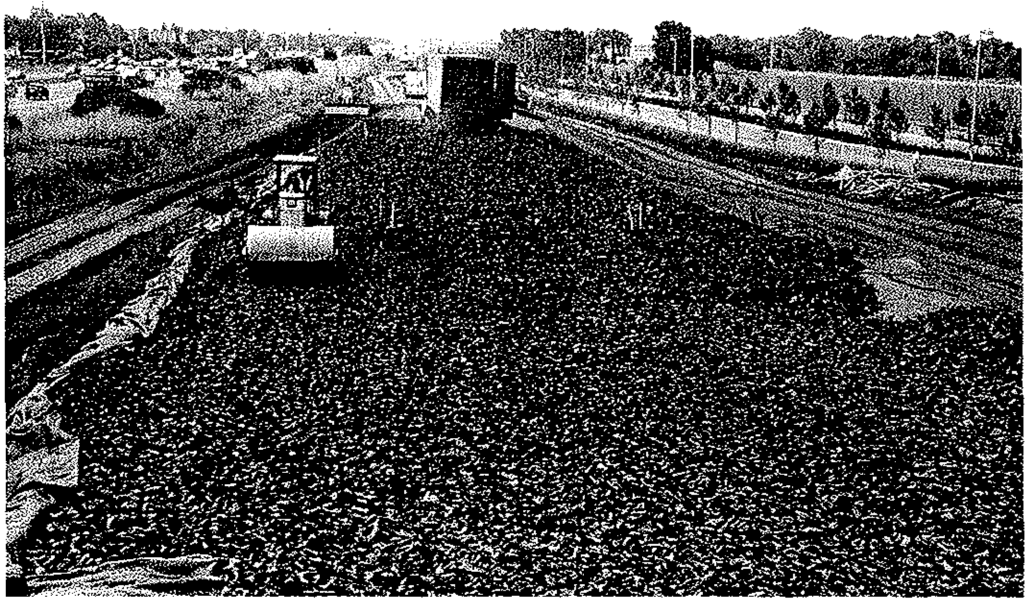

Fig. V-10. Overall project layout, Dixon Landing Interchange.

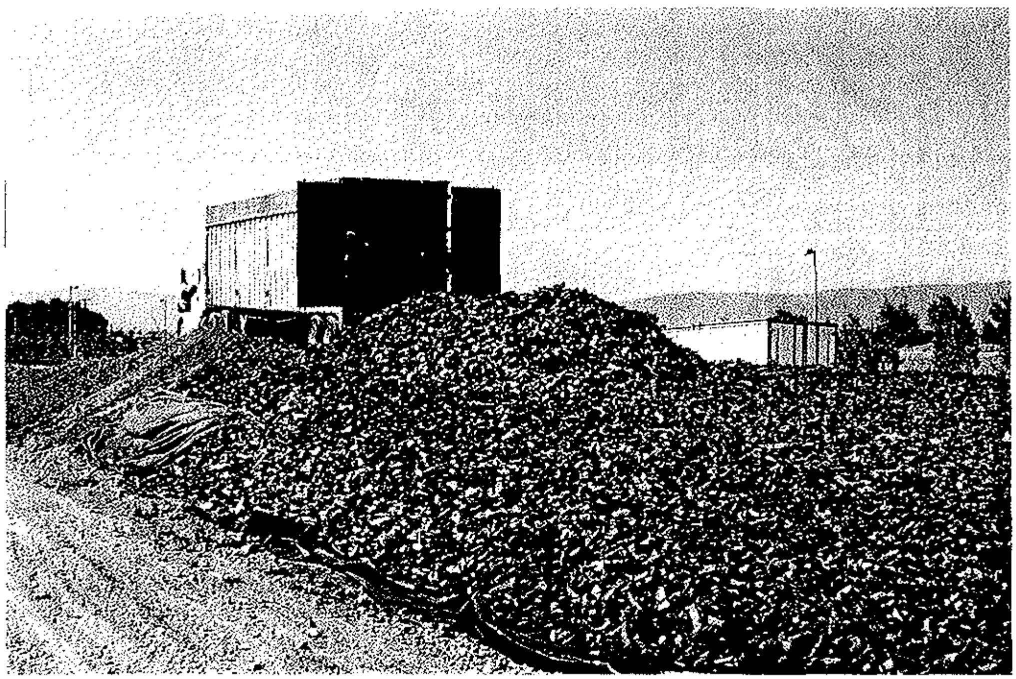

Fig. V-11. Unloading tire shreds from walking floor trailer, Dixon Landing Interchange.

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Fig. V-12. Spreading tire shreds with bulldozer, Dixon Landing Interchange.

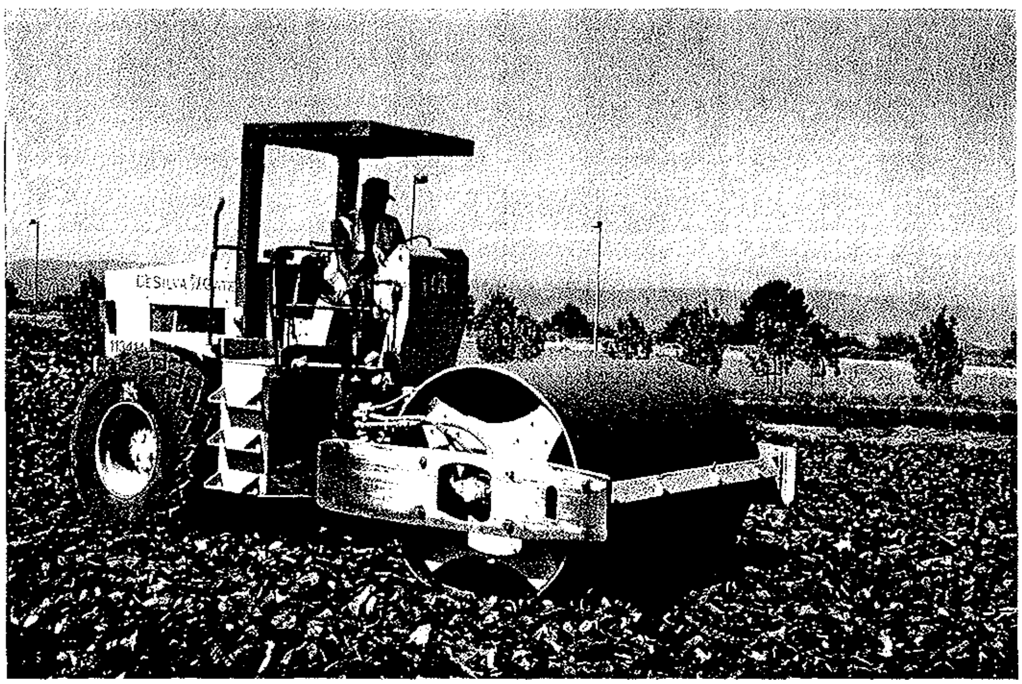

Fig. V-13. Compacting tire shreds with 10-ton roller, Dixon Landing Interchange.

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Fig. V-14. Geotextile separation layer, Dixon Landing Interchange (Photo courtesy of IT Corp.)

Fig. V-15. Soil cover on sides of embankment, Dixon Landing Interchange.

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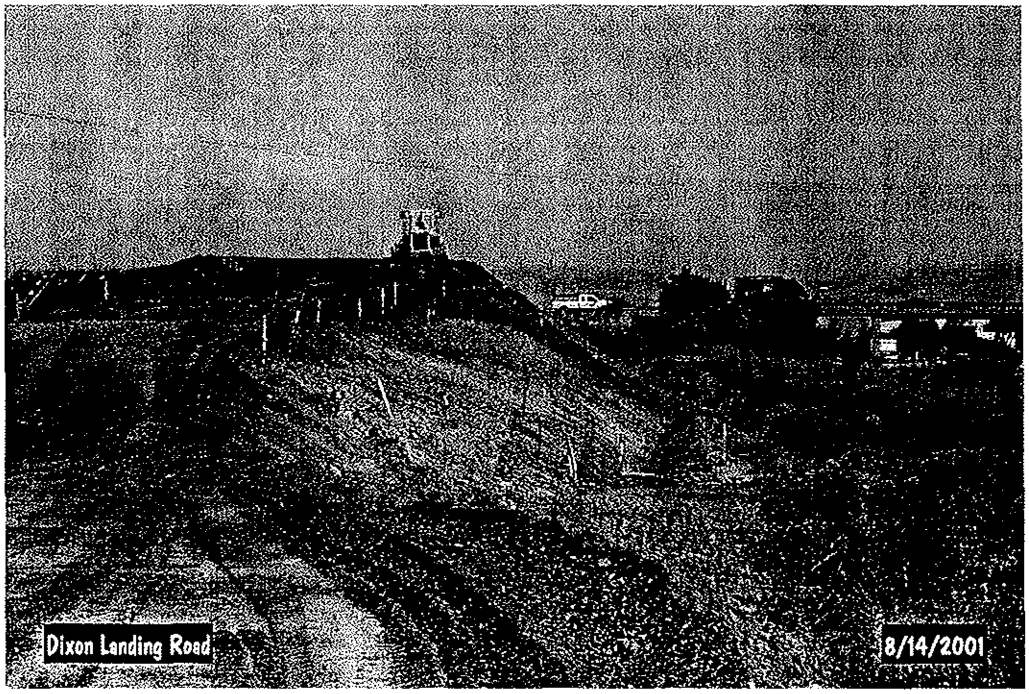

Fig. V-16. Completed embankment, Dixon Landing Interchange (photo courtesy of IT Corp.)

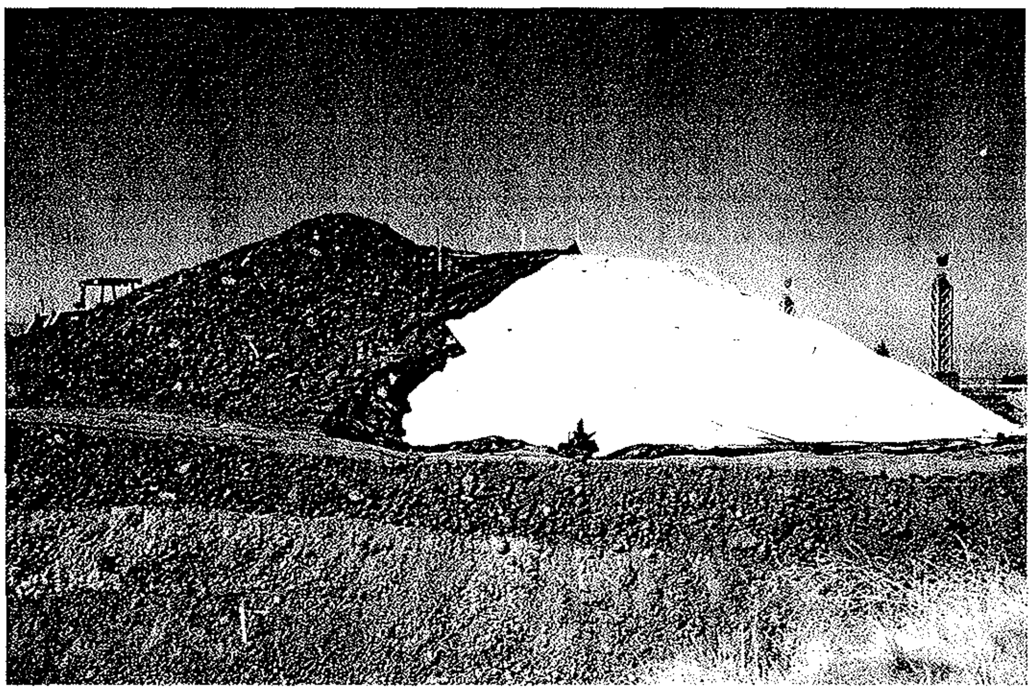

Fig. V-17. Lightweight aggregate, Dixon Landing Interchange.

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C. Case history - North Yarmouth, Maine

1. Project is located on the approach fill for a bridge on Route 231 in North Yarmouth, Maine; this is a secondary state highway with an ADT of 1250 with only 10% being heavy trucks; there was one travel lane in each direction with a very narrow breakdown lane (Humphrey and Nickels, 1994; Nickels, 1995; Humphrey and Nickels, 1997)

2. There were two objectives of this project

    a) Determine the effect of a layer of compressible tire shreds on pavement performance

    b) Determine the effect of tire shreds placed above the water table on groundwater quality - we'll talk about this in a later section

3. Design of project

    a) The tire shreds layer was 2-ft thick; tire shreds covered with common borrow; one gradation test showed that it was sand with a trace of silt; this was followed by 25-in. of base aggregate (clean gravely sand); the total thicknesses of soil cover were 2.5 ft, 3.5 ft, and 4.5 ft; the pavement thickness was 5 in.

    b) Two types of tire shreds were used: 3-in. maximum size and 12-in. maximum size

    c) Tire shreds completely wrapped in geotextile to prevent infiltration of surrounding soil

    d) Typical sections are shown in Figs. V-8 and V-9; there were a total of four tire shred sections and one control section; test section configuration is summarized in Table V-1

    e) The total length of the tire shreds sections were 400-ft, so it was a very small project; but used 100,000 tires

Table V-1. Summary of North Yarmouth Test Section Configuration

Section	Tire shred type	Thickness of layer (in.)			
		Tire shreds	Borrow Cover	Subbase course	Surface course
1	B	24	5	25	5
2	A	24	17	25	5
3	A	24	29	25	5
4	A	24	5	25	5
Control	----	----	5	25	5

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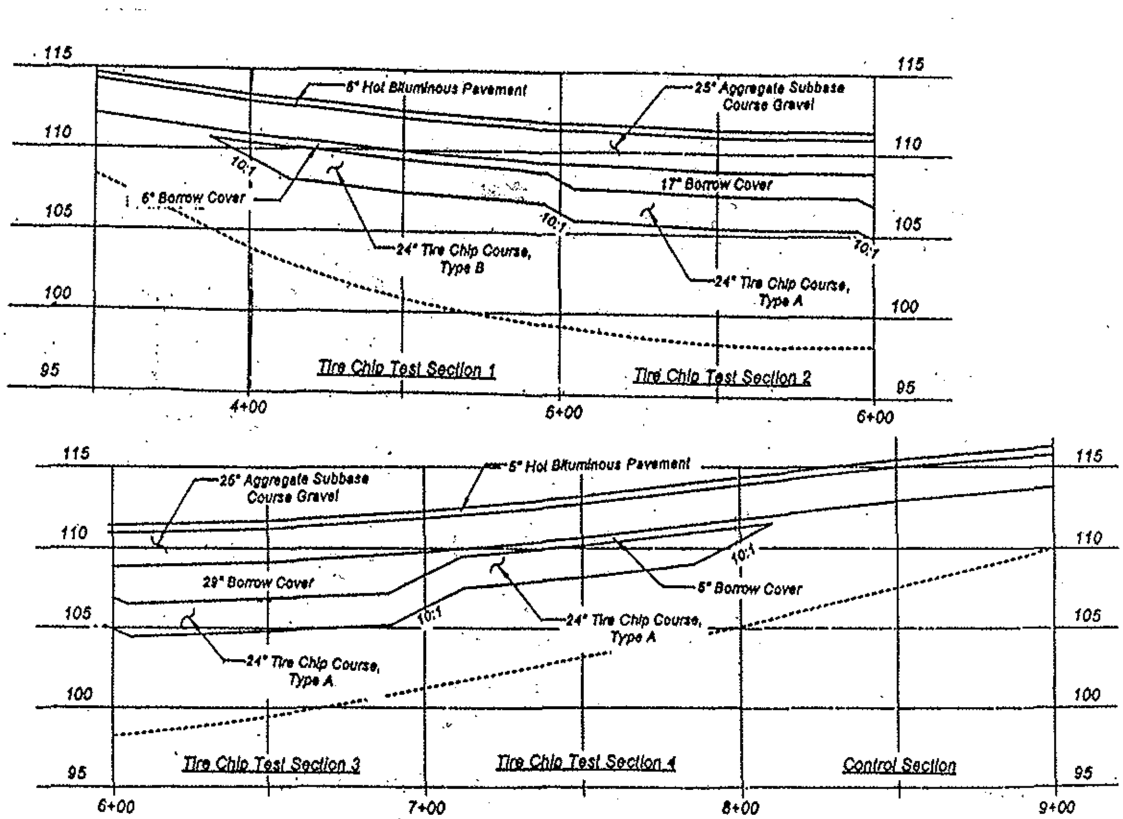

Fig. V-8. North Yarmouth field trial – longitudinal section (Nickels, 1995)

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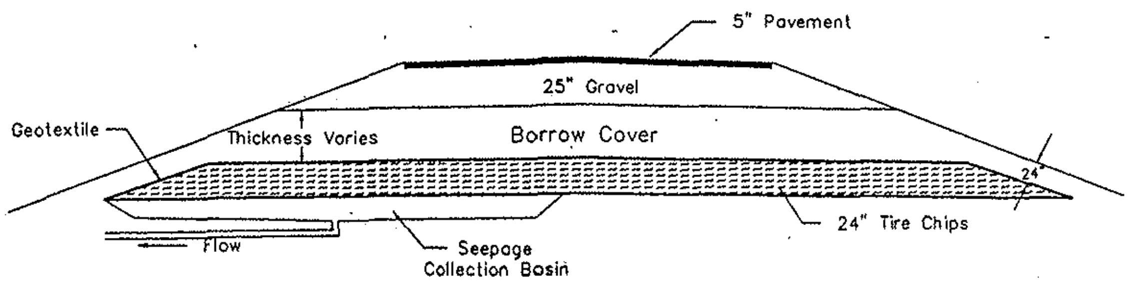

Fig. V-9. North Yarmouth field trial - cross section (Nickels, 1995)

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4. Construction

   a) Tire shreds spread in 12-in. thick lift with medium-sized bulldozer; easy to spread 3-in. shreds in desired lift thickness; the "12-in." maximum size shreds contained numerous oversize pieces that made it impossible to spread 12-in. maximum size shreds to desired lift thickness

   b) Four types of compaction equipment were used: vibratory smooth drum roller with static weight of 10 tons; wide-track bulldozer with contact pressure of 4.48 psi; loaded 14 yd^3 dual rear axle dump truck; vibratory tamping foot roller with static weight of 7.4 tons

      (1) Vibratory smooth drum roller, bulldozer, and vibratory tamping foot roller were effective for compacting tire shreds - of the three it was hard to say which one was best

      (2) Loaded dump truck was ineffective; it sank deeply into tire shreds and tended to fluff them up rather than compact them; also problem with flats!

      (3) The in-place total (moist) unit weight, before the overlying soil cover was placed, was 43 pcf for the 3-in. minus shreds and 38 pcf for the 12-in. minus shreds

   c) Borrow cover, base course, and pavement were placed using conventional construction techniques

E. Case history - Township 31MD, Maine

1. The project was similar to the North Yarmouth Trial; it is located on Route 9 between Bangor and Calais, Maine; it is a secondary state highway with an ADT of 3000; in one direction there was a travel lane and a passing lane while in the other direction there as a travel lane and a full-width breakdown lane (Humphrey and Nickels, 1994; Nickels, 1995)

2. The test section configuration is summarized in Table V-2; typical sections are shown in Figs. V-10 and V-11

   a) Total soil cover thickness varied from 4-ft to 8-ft; common borrow cover was a very silty gravely sand

   b) The pavement in the travel lanes was 9-in. thick

3. An evaluation of compaction results showed that vibratory tamping foot and vibratory smooth drum rollers were equally effective; these were somewhat more effective than compaction with a bulldozer

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Table V-2 Summary of TWP31-MD Test Section Configuration

Section	Tire shred type	Thickness of layer (in.)			
		Tire shreds	Borrow Cover	Subbase course	Pavement (travel lanes)
Control	----	----	----	25	9
1	A	24	24	25	9
2	A	24	48	25	9
3	A	24	72	25	9
4	B	24	48	25	9

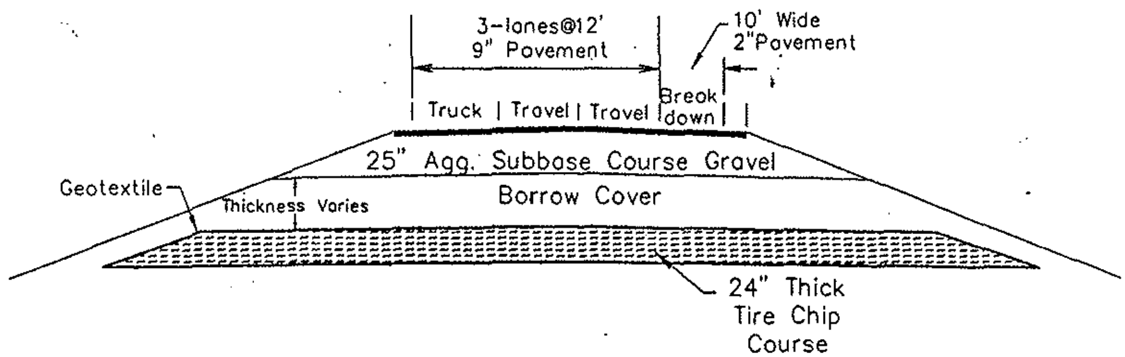

Fig. V-10. TWP31-MD field trial - cross section (Nickels, 1995)

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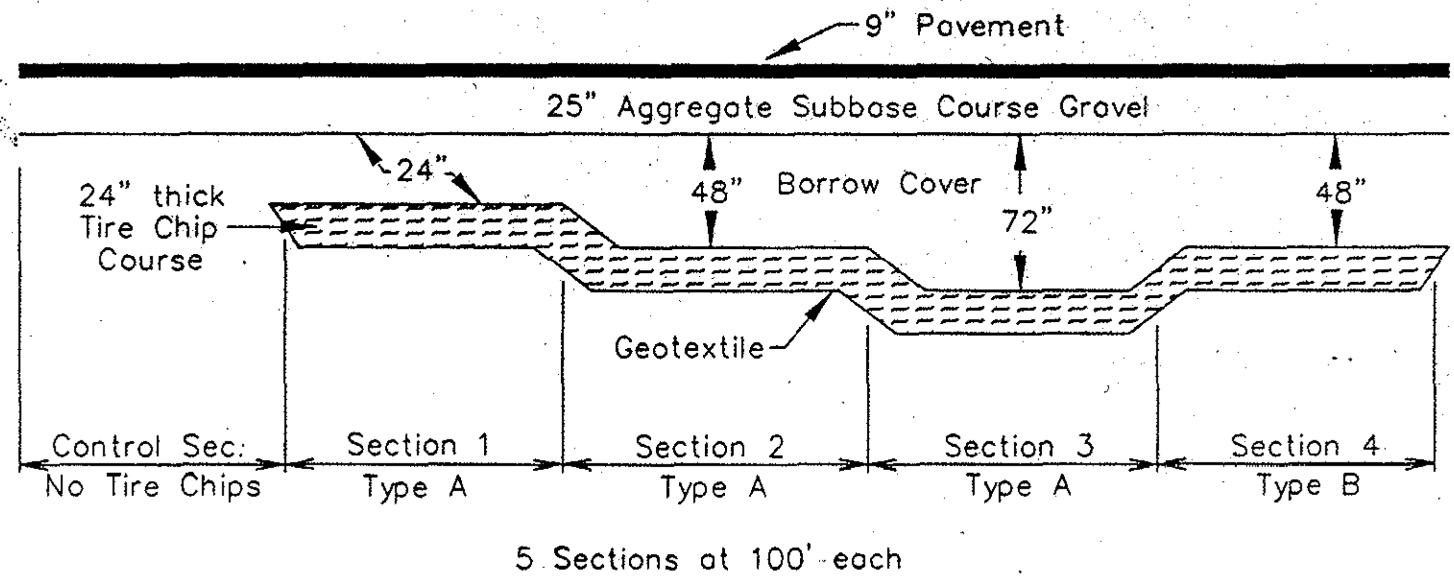

Fig. V-11. Twp31-MD field trial – longitudinal section (Nickels, 1995)

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F. Effect of tire shreds on pavement durability

1. An important concern when using tire shreds as fill for highway construction is the effect that the compressible tire shreds will have on the durability of the overlying pavement; all experience to date has been with hot mix bituminous pavement
2. Questions may be broken down as follows
   a) What effect does tire shred layers have on pavement deflections, and more importantly, tensile strains in the bottom of the pavement? As tensile strains increase the service life of the pavement decreases
   b) What is the target service life?
   c) What is the minimum thickness of overlying soil cover needed to obtain the target service life?

G. Pavement deflections

1. The University of Maine measured pavement deflections on the North Yarmouth and T31MD field trails using the following methods

   a) Modified Benkelman beam - measures pavement deflections caused by a loaded, single rear axle, dump truck; modified so that shape of deflection basin could be measured

   b) Road rater - measures pavement deflections caused by vibrating load applied to pavements

   c) Heavy weight deflectometer (HWD) - measures pavement deflections caused by 9,000 lb weight impacting on an 18-in. diameter plate

2. We will look at results from Benkelman beam; diagram of Benkelman beam apparatus is shown in Fig. V-12

3. Measured deflection basins for the North Yarmouth field trial are shown in Fig. V-13

   a) Deflections increase as thickness of overlying soil cover decreases; deflections are greater for the 12-in. minus tire shreds (Type B) than for the 3-in. minus tire shreds (Type A)

   b) Maximum deflection for Section 4 (30 in. of soil cover over 3-in. minus tire shreds) was 0.10 in.; this is three times greater than the control section

   c) Maximum deflection for Section 1 (30 in. of soil cover over 12-in. minus tire shreds) was 0.13 in.; this is four times greater than the control section

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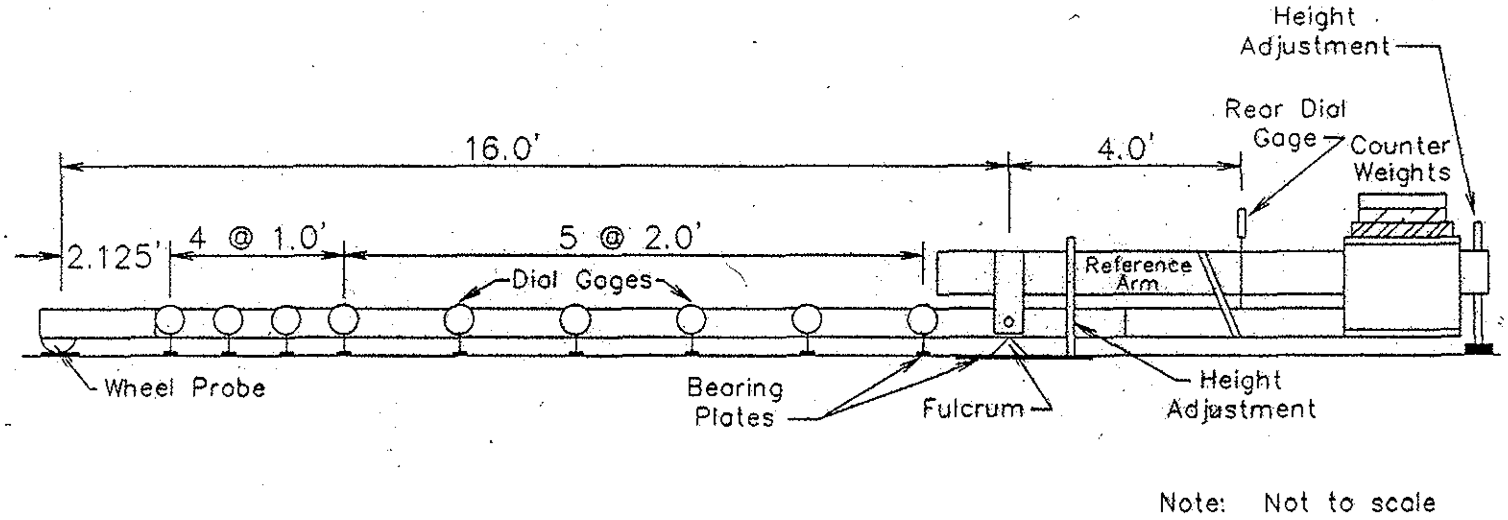

Fig. V-12. Modified Benkelman beam used to measure pavement deflections (Nickels, 1995)

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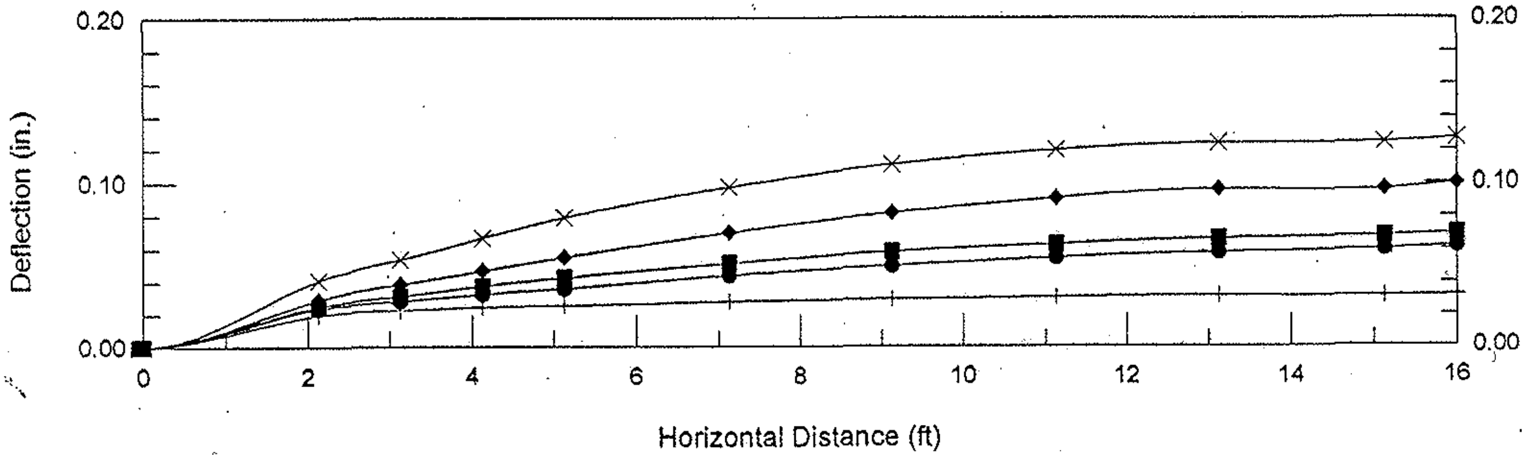

NOTES:

1. Section 1 - 30" gravel cover, type B
2. Section 2 - 42" gravel cover, type A
3. Section 3 - 54" gravel cover, type A
4. Section 4 - 30" gravel cover, type A

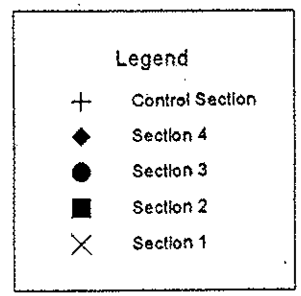

Fig. V-13. Summary of maximum deflections obtained from each section for North Yarmouth (Nickels, 1995)

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d) Comparing shape of deflection basins - control section has narrow basin with diameter of about 2 ft; in contrast tire shred sections have a broad flat deflection basin - this suggests that even through the deflections are much greater for the tire shred sections, there may only be a small increase in the tensile strains in the bottom of the pavement

4. Measured deflection basins for the T31MD field trial are shown in Fig. V-14

   a) Deflection for the control section is about the same as for the North Yarmouth trial; however, deflections for the tire shred sections are less than for North Yarmouth

   b) Other observations are the same as for the North Yarmouth field trial

5. Normalized deflection versus soil cover thickness is shown in Fig. V-15; normalized deflection is the measured deflection of the tire shred section, divided by the measured deflection of the control section

   a) Data from both projects follow the same trend of decreasing deflection with increasing soil cover thickness

   b) Type B tire shreds (12-in. maximum size) produced more deflection than the Type A (3-in. maximum size) shreds with the difference being more pronounced at thinner soil covers

H. Pavement tensile strains

1. The shape of the deflection basins was modeled using KENLAYER, a numerical solution for nonlinear elastic multilayer systems under a circular loaded area (Huang, 1993). The model was used to estimate the tensile strains in the bottom of the pavement. (Humphrey and Nickels, 1997)

2. The following relationship was used to represent the modulus of the soil

$$E = K_1 \theta^{K_2}$$

where θ is the first stress invariant in kPa, and K_1 and K_2 are experimentally determined constants. The subbase and common borrow overlying and beneath the tire shred layer were a mixture of sand and gravel. Rada and Witczak (1981) recommend $K_1 = 11{,}100$ kPa (4300 psi) and $K_2 = 0.53$ for this soil type. The Poisson's ratio was taken to be 0.29 and the coefficient of lateral earth pressure at rest was taken to be 0.40.

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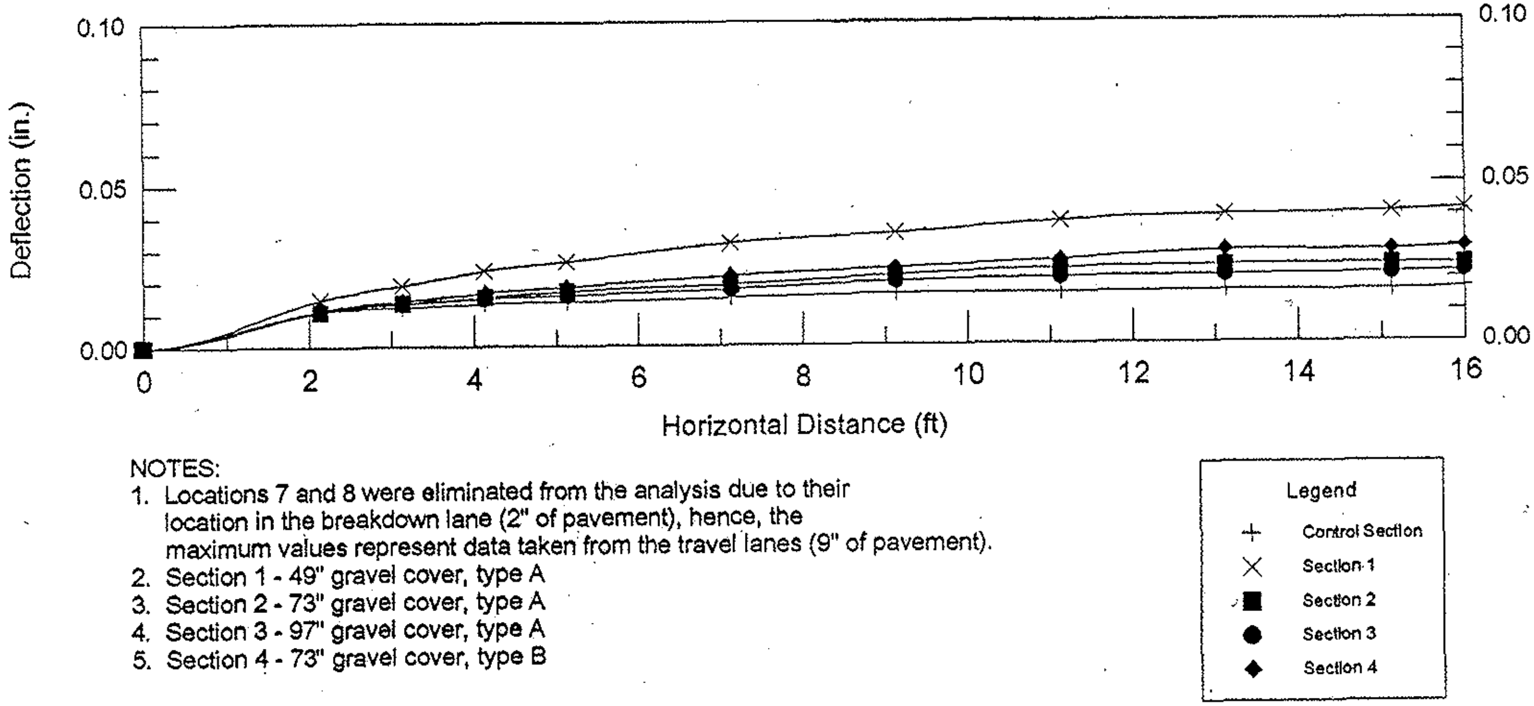

Fig. V-14. Summary of the maximum deflection basins obtained from each section for TWP31-MD (Nickels, 1995)

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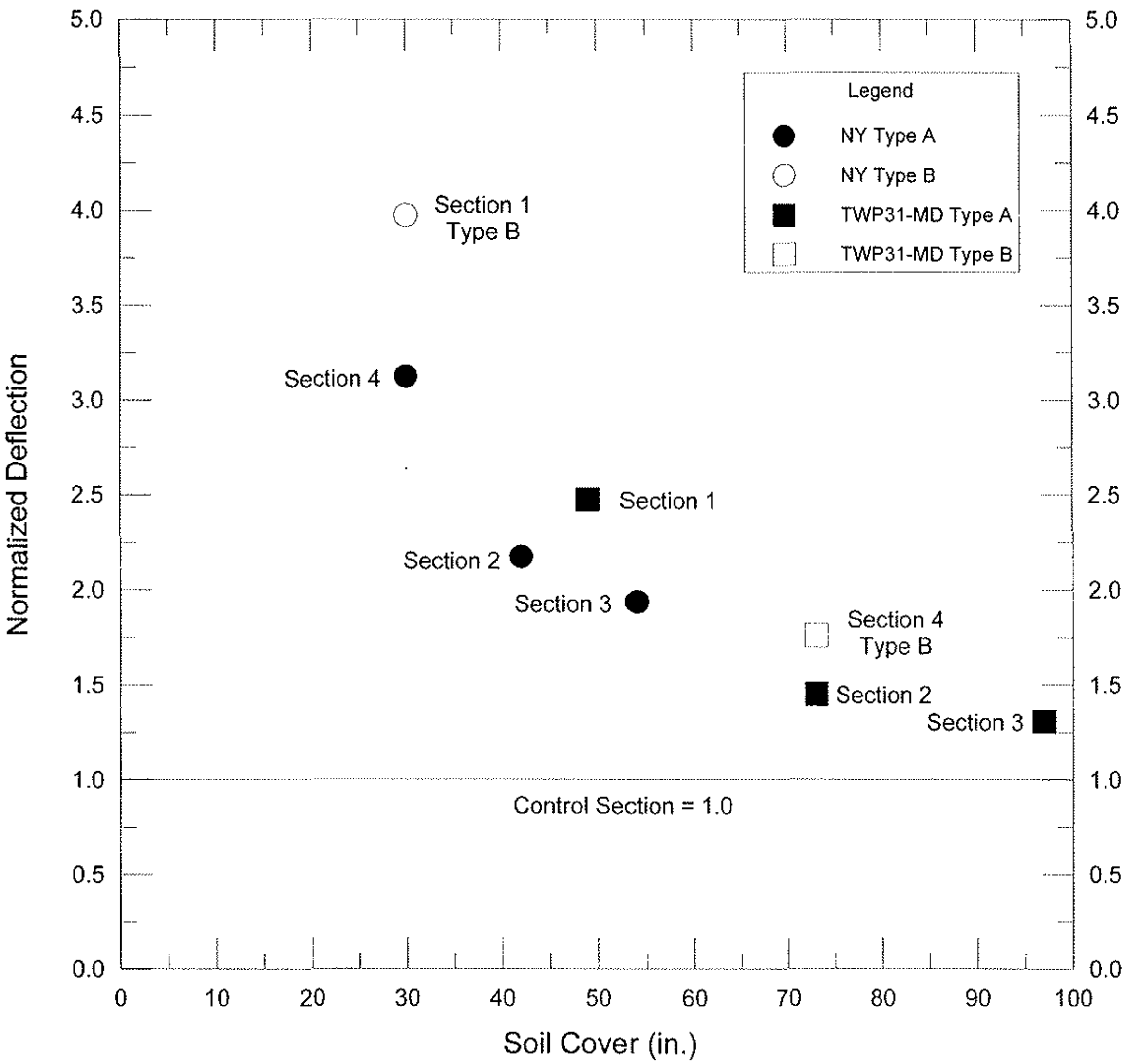

Fig. V-15. Normalized pavement deflections for North Yarmouth and TWP31-MD field trials (Nickels, 1995)

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3. The pavement was taken to be linear elastic. The pavement modulus was adjusted to obtain a reasonable match between the measured and computed deflection basins in the control section. Good agreement was obtained for a pavement modulus of 276 MPa (40,000 psi) and Poisson's ratio of 0.35. While this modulus is relatively low, it is reasonable for deflections measured on sunny days in August when the air temperature was in excess of 29°C (84°F).

4. The modulus of tire shreds was found to follow the same non-linear relationship used for soils as given above. K_1 was found to be 4.4 kPa (9.0 psi) and K_2 was found to be 1.16 using a large scale one-dimensional compressibility apparatus instrumented to measure lateral pressure (Nickels, 1995). Tire shreds are three orders of magnitude more compressible than soil.

5. The load was applied to the pavement as two circular loaded areas with a radius of 96 mm (3.78 in.) and a contact pressure of 689 kPa (100 psi). The center to center spacing of the two loaded areas was 343 mm (13.5 in.) to simulate a dual wheel.

6. Predicted pavement deflections for Section 4 and the control section are compared to deflections measured in August, 1994, and a second set of measurements taken in August, 1995 (see Figure V-15). The agreement is very good, although deflections are slightly overpredicted in the control section. Very good agreement was also obtained for Sections 2 and 3. Section 1 contains the larger Type B shreds, whose compressibility has not been measured in the lab, so no analysis was done for this section.

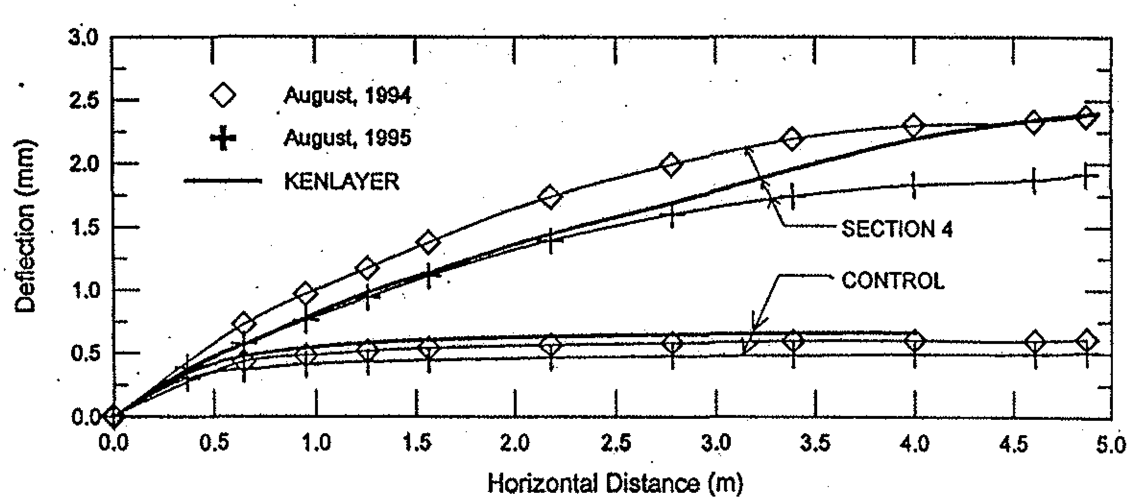

Fig. V-16. Comparison of measured and predicted pavement deflection basins, North Yarmouth Test Section.

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7. The maximum tensile strain in the bottom of the pavement was essentially the same in the control section and the tire shred sections, suggesting that for the soil cover thicknesses and tire shred thickness used in the field trial, the tire shreds will not be detrimental to pavement longevity.

8. Additional analyses were performed to estimate how thin the soil cover could be before detrimental tensile strains developed in the bottom of the pavement. A pavement thickness of 127 mm (5 in.) and a tire shred layer thickness of 610 mm (2 ft) were used. The results are summarized in Table V-3. The analyses indicate that there is a negligible effect on tensile strains for cover thicknesses greater than 457 mm (18 in.). It is expected that a greater cover thickness would be required for pavements with a modulus greater than 276 MPa (40,000 psi).

Table V-3. Effect of cover thickness on maximum tensile strains in bottom of pavement (Humphrey and Nickels, 1997).

Overlying soil cover (mm)	Maximum tensile strain (ε_t) (%)	Ratio of $(\varepsilon_t)/(\varepsilon_t)_{soil}$
0	-0.63	13.0
229 (9 in.)	-0.099	2.0
457 (18 in.)	-0.051	1.0
610 (24 in.)	-0.044	0.9
762 (30 in.)	-0.042	0.9
All soil	-0.048	1.0

I. Choice of overlying soil cover thickness

1. Soil cover thicknesses used in initial field trials constructed in 1993 and 1994 have ranged from 2.5 ft to more than 6 ft; so far there have been no reports of pavement distress but time in service may be too short for problems to have developed; test sections with soil cover as thin as 1 ft were constructed in 1996. Cracking has occurred in the sections with 1 ft of cover, but sections with 19 in. of cover are performing satisfactorily so fat – but it is too early to assess performance.

2. For high modulus asphaltic concrete pavements (pavement modulus = 7,000 MPa; 1,000,000 psi) UMaine results suggest that soil cover should be greater than 3 or 4 ft, if possible; if some reduction in pavement service life is acceptable, then it may be possible to use less soil cover

3. For low modulus asphaltic concrete pavements (pavement modulus = 276 MPa; 40,000 psi) UMaine results suggest that soil cover should be greater than 2 ft, if possible; if some reduction in pavement service life is acceptable, then it may be possible to use less soil cover.

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4. Tire shreds with a maximum size of 12in. are more compressible than tire shreds with a maximum size of 3 in., so soil cover thicknesses greater than recommended above may be required for larger size shreds.

I. Choice of unit weight of tire shreds

1. The unit weight of tire shreds increases as the thickness of soil cover and the thickness of the tire shred layer increases

2. The unit weight for your job can be computed using the procedure given in Section IV.D.

J. Slope stability and tire shreds

1. The shear strength of tire shreds for slope stability calculations should be chosen with care

2. The shear strength is probably high, but there is some controversy as to whether it should be measured with direct shear test or triaxial test

3. For failure surfaces that pass only through the tire shred layer and the overlying soil cover, it is unlikely that stability will be a major concern provided a reasonable sideslope is used; the strengths given Section IV.H

4. It may require large deformations for tire shreds to develop their shear strength; for some applications these large deformations are acceptable; however, for tire shreds embankments constructed on sensitive clay foundations large deformations are unacceptable and a very low (or zero) shear strength of the tire shreds should be used

K. Important design details

1. For paved applications, tire shred layer must be completely wrapped in geotextile to prevent surrounding soil from being washed into the voids between the tire shreds; seams between rolls of geotextile should be overlapped a minimum of 18 in.; the filtration properties of the geotextile should be compatible with the gradation of the surrounding soil as described in Federal Highway Administration Geotextile Design Manual

2. The tire shreds will compress as the overlying soil cover is placed, so you need to overbuild top of tire shred layer so that final compressed elevation of tire shreds will be the desired value; for a recently completed job in Maine with a 14 ft tire shred fill covered by 6 ft of soil, the tire shred layer was overbuilt by 1.5 ft; a procedure to calculate the overbuild for your project was given in Section IV.D. An alternate procedure, applicable to Type B tire shreds, is given in Appendix II.

3. If the soil immediately above the tire shreds is cohesionless, it will compact much better if the soil is moist; dry granular soils over tire shreds will not compact

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4. There is some time dependent settlement of tire shred layer under the weight of the overlying soil cover – for tire shred layers that end at an immovable object, should allow 2 months after placement of the overlying soil cover for time dependent settlement to occur prior to final grading and paving; may want to consider a small surcharge during this period, say 1 to 2 ft thick; for tire shred fills that can be gradually tapered to zero thickness, a shorter waiting time is acceptable (could be as short as two weeks if the construction schedule is very tight).
5. Mixtures of tire shreds and soil
    a) Some engineers are concerned with the compressibility of tire shreds and the effect this could have on pavement performance; to reduce the compressibility of tire shreds, they advocate using mixtures of tire shreds and soil; this reduces compressibility of tire shreds but also increases unit weight
    b) I am not in favor of using mixtures of tire shreds and soil
        (1) Difficult to mix tire shreds and soil; tire shreds have low specific gravity compared to soil, so tire shreds tend to end up on top of lift and soil ends up on bottom
        (2) Adds to construction cost
        (3) If poor mixing of tire shreds and soil, the soil will migrate into voids between tire shreds with time leading to long term settlement problems
        (4) The more soil you mix with the tire shreds, the more you loose the beneficial properties of the tire shreds

L. Unpaved roads

1. If the road is unpaved, deflections of the road surface are not a problem
2. Soil cover must be thick enough to prevent rutting
    a) On dead end road with very low traffic volume, I have successfully used 12 in. of soil cover over 6 in. of tire shreds and 18 in. of soil cover over 12 in. of tire shreds
    b) Required cover thickness probably increases as the thickness of the tire shred layer increases and as the traffic loading increases
3. Some migration of soil into voids between tire shreds may be acceptable, so if you are using 3-in. maximum size shreds, it may be OK to have shreds in direct contact with surrounding soil; with 12-in. shreds, still need geotextile

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VI. RETAINING WALL AND BRIDGE ABUTMENT BACKFILL

A. Case history - University of Maine/NETC Test Wall

1. UMaine constructed world's second largest retaining wall test facility; 16 ft high; 15 ft by 15 ft plan area; after fill is placed use concrete blocks to apply surcharge of 750 psf; a cross section through the facility is shown in Fig. VI-1
2. Tested tire shreds from three producers; two of the shred types were 3-in. maximum size and had no removal of steel belts; the other was 1.5-in. maximum size and had most of the steel belts removed; results are given in (Tweedie, et al., 1998a,b,c)
3. Tire shreds placed in 8-in. lifts and compacted with 2300-lb walk-behind roller (vibrating plate compactors are ineffective for compacting tire shreds)
4. After tire shreds placed, the 750 psf surcharge was applied
5. At rest conditions

   a) At rest lateral pressures measured with load cells and total earth pressure cells; measured earth pressures shown in Fig. VI-2; earth pressure at base of wall was considerably less than would be obtained with gravel

   b) Coefficient of lateral earth pressure at rest was computed from the results and are summarized in Table VI-1; the values of K_o decreases with depth for all loading condition; for the no surcharge case at a depth of 0.5 m (1.6 ft) K_o ranges from 0.93 to 0.99 - this is because K_o is defined as the ratio of the horizontal divided by the vertical stress, but near the surface the vertical stress approaches zero; looking at the other depths at no surcharge and all the depths at surcharges of 12.0 kPa (250 psf), 23.9 kPa (500 psf), and 35.9 kPa (750 psf), the following relationship between K_o and depth was obtained:

Depth	K_o
0.0 m (0.0 ft)	0.45 to 0.58
2.0 m (6.6 ft)	0.32 to 0.33
4.0 m (13.1 ft)	0.24 to 0.27

6. Active conditions

   a) Wall was rotated outward about its base to achieve active earth pressure conditions; rotations up to 0.04H were used; pressures still dropping as this rotation was reached so true active (i.e., minimum) pressures were not achieved.

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b) From a practical viewpoint, rotations greater than 0.01H (0.8 degrees) are seldom tolerable; thus, the discussion will focus on rotations measured at this rotation

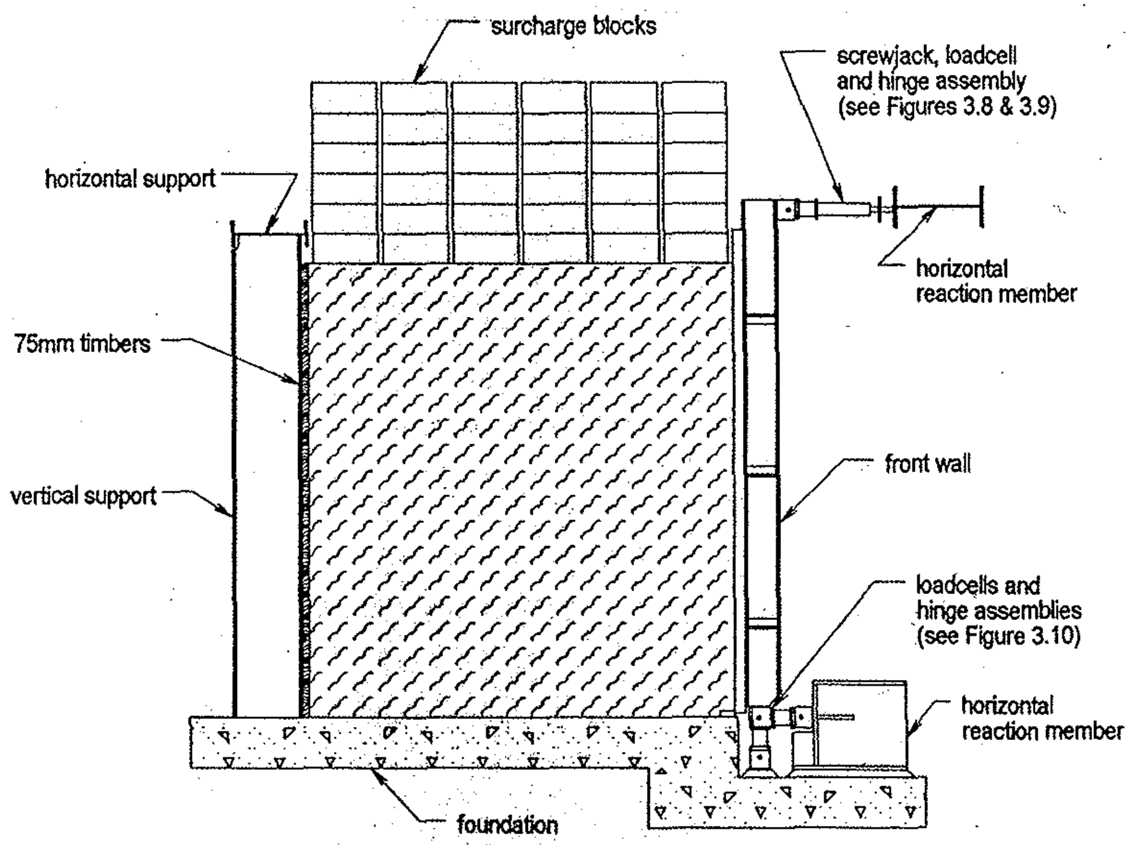

Fig. VI-1. Cross section through University of Maine retaining wall test facility (Tweedie, et al., 1998a)

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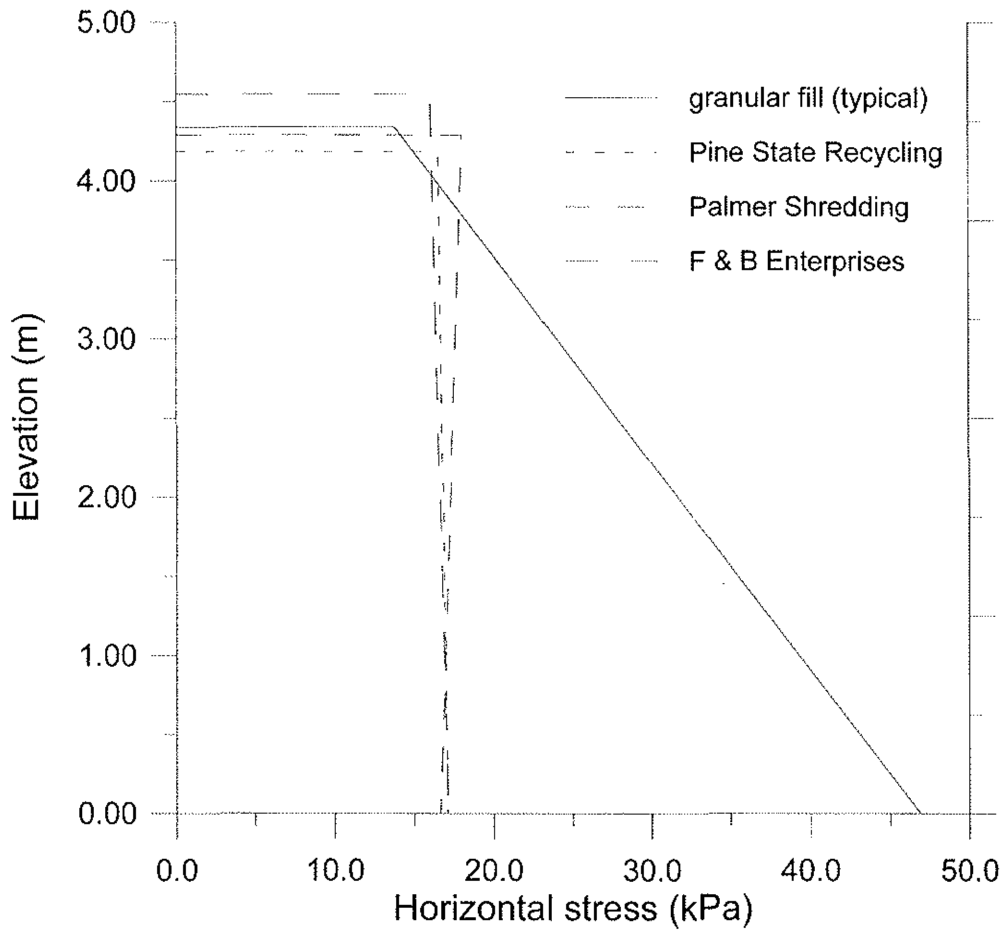

1 m = 3.28 ft, 1 kPa = 20.89 psf

Fig. VI-2. Measured horizontal stress distribution as determined from load cell measurements (Tweedie, et al., 1998a)

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Table VI-1. Coefficient of lateral earth pressure at rest (Tweedie, et al., 1998a)

		Surcharge			
Supplier	Depth (m)	0	12.0 kPa	23.9 kPa	35.9 kPa
Pine State Recycling	0	0.93[a]	0.55	0.46	0.47
	2	0.37	0.32	0.32	0.32
	4	0.28	0.26	0.26	0.25
Palmer Shredding	0	0.94[a]	0.58	0.51	0.51
	2	0.37	0.33	0.27	0.33
	4	0.29	0.27	0.17	0.24
F&B Enterprises	0	0.99[a]	0.51	0.44	0.45
	2	0.39	0.33	0.32	0.32
	4	0.31	0.28	0.26	0.25
Average	0	0.95	0.55	0.47[b]	
	4	0.29	0.27	0.24[b]	

1 m = 3.28 ft, 1 kPa = 20.89 psf

[a] Value Found at a Depth of 0.5 m (1.64 ft)

[b] Average from 12.0 kPa (250 psf) and 35.9 kPa (750 psf) Surcharges

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c) Measured horizontal stress at a rotation of 0.01H and surcharge of 35.9 kPa (750 psf) are shown in Fig. VI-3; for comparison the Rankine active earth pressure for a gravel with a friction angle of 38 degrees; the horizontal pressure from tire shreds is about 40% less than for granular soil

d) The active earth pressure coefficient (K_a) at a rotation of 0.01H and surcharge of 35.9 kPa (750 psf) was approximately constant with depth and ranged from 0.22 to 0.25 at all depths for the three types of tire shreds.

7. Interface friction between tire shreds and concrete face of the wall ranged from 30 to 32 deg.; this was determined from a plot of vertical versus horizontal force acting on the front face of the wall; a typical plot is shown in Fig. VI-4.

B. Case history – North Abutment Fill, Topsham, Maine

1. North Abutment of the 300-m long Merrymeeting Bridge in Topsham, Maine is underlain by up to 50 ft of soft marine clay; factor of safety of existing slope against a deep seated slope failure through the marine clay was near one – the lowest cost solution was to excavate a portion of the existing slope and replace it by 14 ft of tire shreds covered by 6 ft of soil. Longitudinal cross section is shown in Fig. VI-5. (Humphrey, et al, 1998)

2. Using the procedure given in Section IV.D., it was estimated that the tire shred layer would compress 1.5 ft under the weight of the overlying soil and pavement, so the layer was overbuilt by this amount. In addition, the contractor was required to wait 60-days after placement of the overlying soil before beginning paving.

3. Four types of instruments were installed: pressure cells cast into the back face of the abutment wall; and vibrating wire settlement gauges, settlement plates and temperature sensors placed in the tire shred fill. Vibrating wire pressure cells were installed to monitor lateral earth pressure against the abutment wall.

4. The tire shred fill compressed about 14.6 in. (370 mm) during placement of the overlying soil cover. Placement of the soil cover completed on October 15, 1997. In the next 60 days the fill settled an additional 5.3 in. (135 mm). Between December 15, 1996 and December 31, 1997 the fill underwent an additional (0.6 in.) (15 mm) of time dependent settlement. The rate of settlement had decreased to a negligible level by late 1997. The total compression of the tire shred fill was 20.5 in. (520 mm) which was 13% greater than the 18 in. (460 mm) that was anticipated based on laboratory compression tests. The difference is due mostly to time dependent settlement which is not accounted for in the method presented in Section IV.D.

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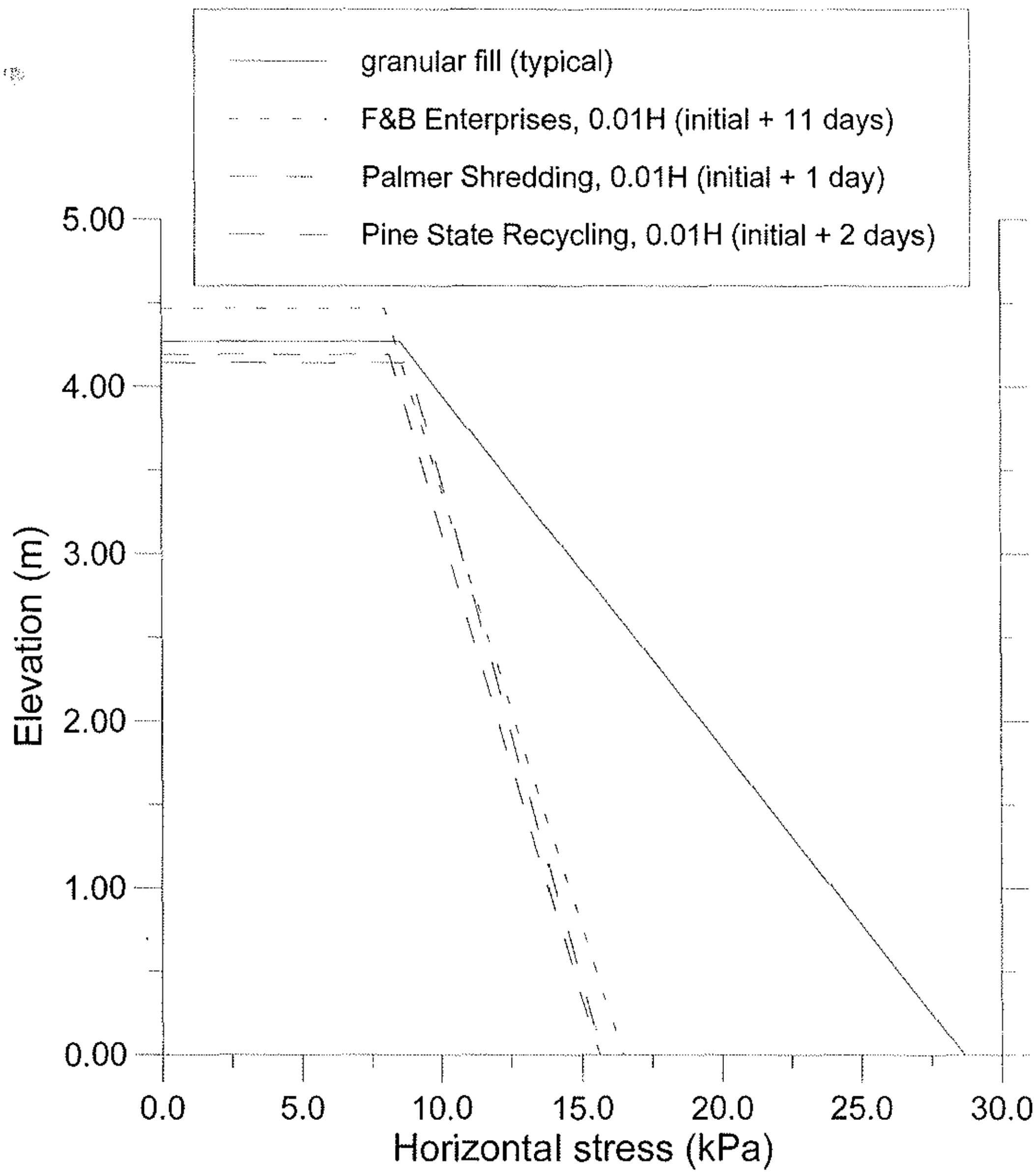

Fig. VI-3. Comparison of at active earth pressures for tire shreds and conventional soil backfill with a 750 psf surcharge (Tweedie et al., 1988a)

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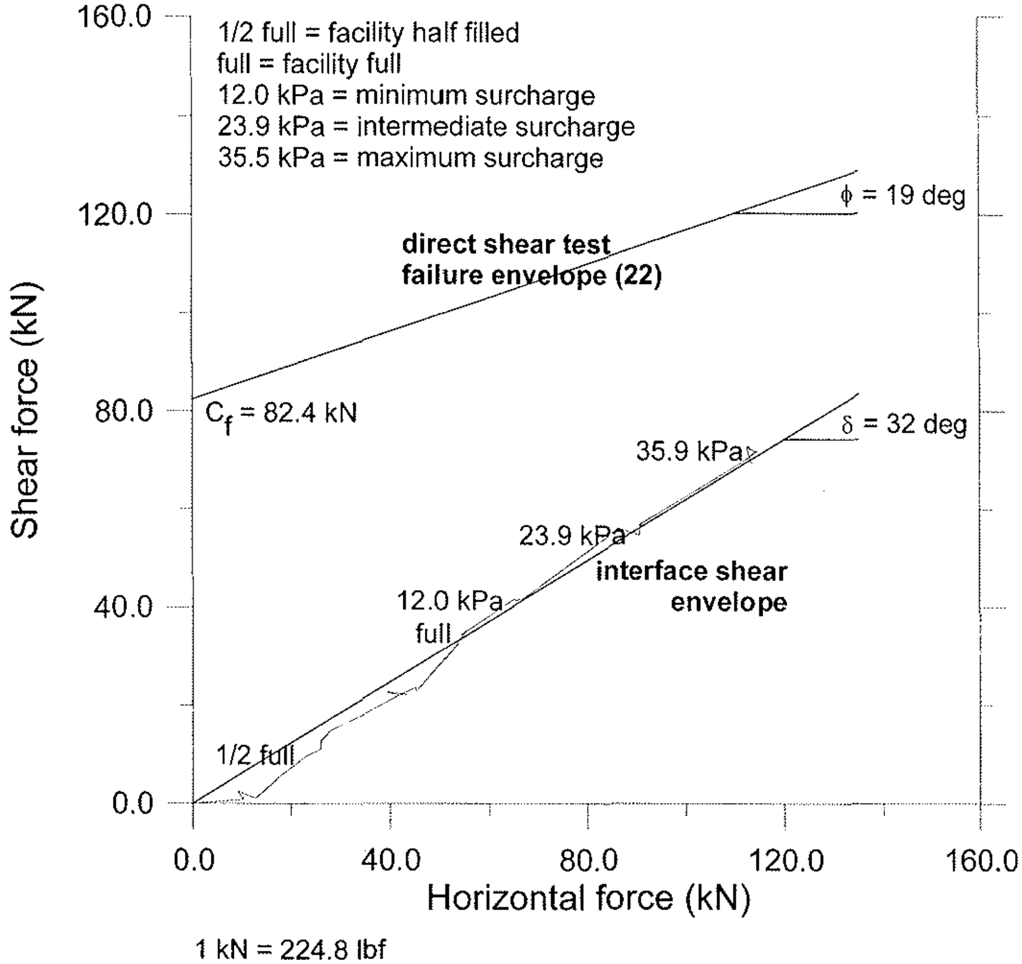

Fig. VI-4. Shear force versus horizontal force for Palmer Shredding tire shreds; the failure envelope from direct shear tests on tire shreds is also shown for comparison (Tweedie et al., 1998a)

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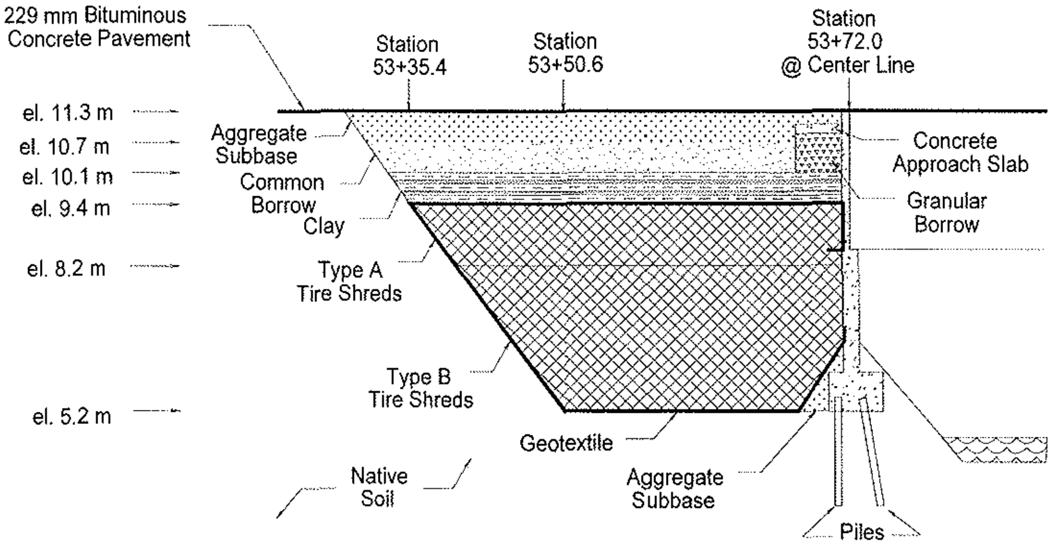

Fig. VI-5. Cross section through North Abutment tire shred fill.

5. The final compressed unit weight of the tire shreds was about 56 pcf (0.9 Mg/m^3, which is very close to the value of 57 pcf (0.91 Mg/m^3) predicted prior to construction.

6. The lateral pressure at the completion of tire shred placement (10/3/96) and completion of soil cover and surcharge placement (10/9/96) is summarized in Table VI-2. Lateral pressures on 10/31/96 are also shown.

   a) At completion of tire shred placement, the pressures increased as the elevation of the cell decreased. However, at completion of soil cover and surcharge placement, the pressures recorded by cells PC1-1, PC1-2, and PC1-3 were nearly constant with depth and ranged between 356 and 410 psf (17.05 and 19.61 kPa). These findings are consistent with at-rest conditions measured by Tweedie, et al. (1998a,b).

Table VI-2. Summary of lateral pressures on North Abutment Wall.

	PC1-1	PC2-1	PC1-2	PC2-2	PC1-3	PC2-3
Date	Cell elev. = 6.70 m		Cell elev. = 7.77m		Cell elev. = 8.84 m	
10/3/96[2]	7.84[1]	7.41	6.04	7.27	2.62	1.41
10/9/96[3]	17.04	20.04	19.61	30.22	17.05	10.91
10/31/96	18.27	21.05	20.98	32.84	20.24	12.31

[1]Horizontal pressure in kPa. (kPa x 20.885 = psf)
[2]Date tire shred placement completed.
[3]Date soil cover and surcharge placement completed.

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b) Cells PC2-1, PC2-2, and PC2-3 showed different behavior. On 10/9/96, cell PC2-2 showed a pressure of 631 psf (30.22 kPa) while cell PC2-1, located only 3.5 ft (1.07 m) lower, was 419 psf (20.04 kPa) and cell PC2-3, located 3.5 ft (1.07 m) above PC2-2, was 257 psf (12.31 kPa). These cells were the less stiff RocTest EPC cells. Large scatter has been observed with EPC cells on an earlier tire shred project (Tweedie, et al., 1998a,b). It is thought to be due, at least in part, to large tire shreds creating a nonuniform stress distribution on the face of the pressure cell. The average pressure recorded by the three PC2 cells was 435 psf (20.85 kPa) which is slightly higher than the PC1 cells.

c) Between 10/9/96 and 10/31/96 the lateral pressure increased by 20 to 40 psf (1 to 2 kPa). The pressures have been approximately constant since that time.

7. Temperature sensor measurements are discussed in a later section of the notes.

C. Case history - Rigid Frame Bridge, Topsham, Maine

1. Three-foot wide vertical strip of tire shreds used as backfill against rigid frame structure as shown in Fig. VI-6 (Humphrey, et al, 1997, 1998)
2. Normally rigid frame structures must be designed for at-rest earth pressures; but for this structure, the roof and batter piles prevented the walls from moving inward thereby preventing the wall from reaching the lower active earth pressures; the purpose of the tire shreds were to act as a compressible layer that allowed the granular borrow to move, thereby mobilizing its strength and developing active earth pressures
3. Project was constructed in June and July, 1996
4. Pressure cells, soil strain meters, slope indicators, and temperature sensors were installed to monitor lateral earth pressures on the wall, as well as the temperature and movement within the tire shred zone; a typical cross section showing the location of the instrumentation is shown in Fig. VI-7; note that soil backfill is placed against the lowest pressure cell
5. The horizontal stress measured by the pressure cells and the approximate fill elevation vs. date is shown in Fig. VI-8; soil is placed against cell PC1-1; tire shreds are placed against the remaining cells; the pressure for tire shred backfill is less than half of the pressure with soil backfill as shown in Fig. VI-8.

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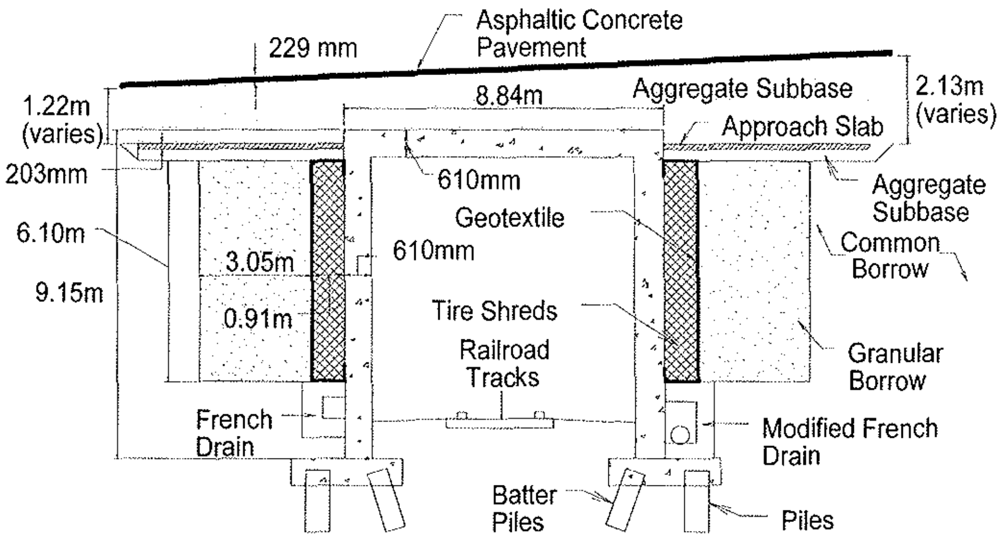

Fig. VI-6. Cross section of rigid frame bridge showing location of tire shred zone (Humphrey, et al., 1998)

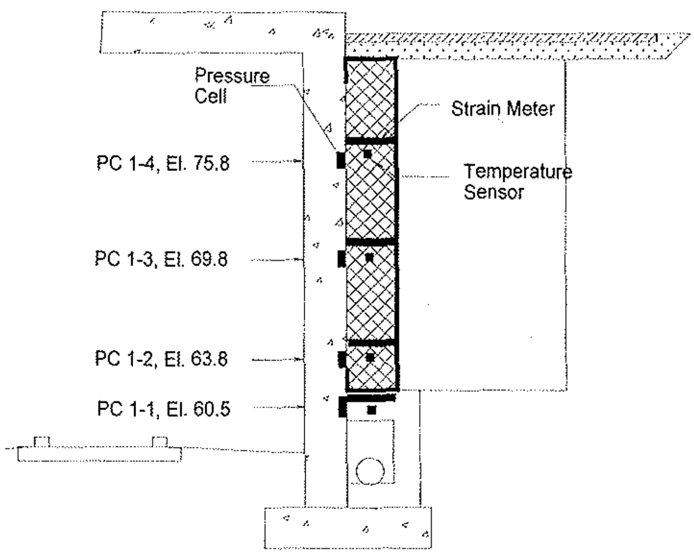

Fig. VI-7. Cross section showing location of instrumentation at station 1004+50 (Humphrey, et al., 1998).

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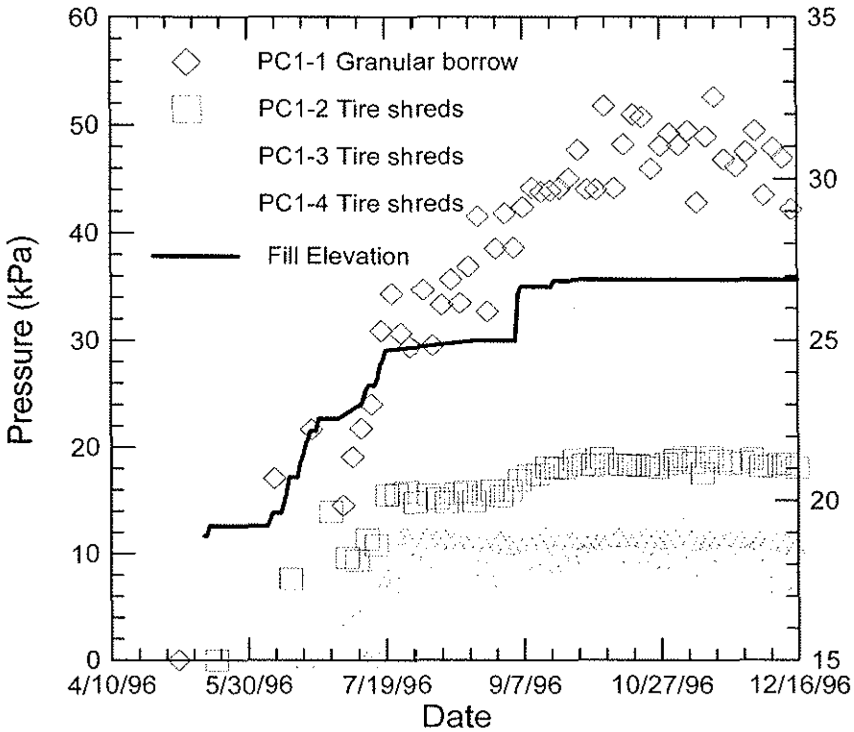

Fig. VI-8. Horizontal stress as measured by the pressure cells and approximate fill elevation versus date (Humphrey, et al., 1998)

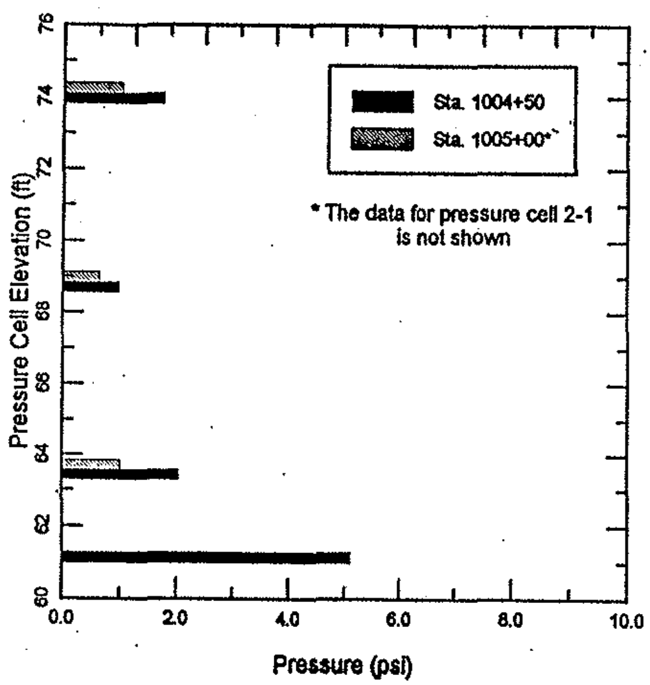

Fig. VI-9. Comparison of pressures measured on September 1, 1996 (Humphrey, et al., 1998).

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D. Case History – Route 91 Retaining Wall, Riverside, CA

1. Tire shreds were used as backfill behind a cantilever retaining wall in Riverside, CA. The retaining wall was needed to allow for widening of Route 91 without encroaching on adjacent property. The project was constructed in summer and fall, 2003.

2. The structural design of the wall was in accordance with Caltrans standard specifications. The wall height is approximately 12 ft (3.6 m).

3. Tire shred layer was 9.8 ft (3 m) thick as shown in Figure VI-10. The tire shreds were completely enclosed in a geotextile to prevent intrusions of soil into the tire shreds. The tire shred section was 262 ft (80 m) long. It required approximately 1130 yd^3 (867 m^3) of Type B tire shred fill. This is equates to 76,500 PTE (passenger tire equivalents).

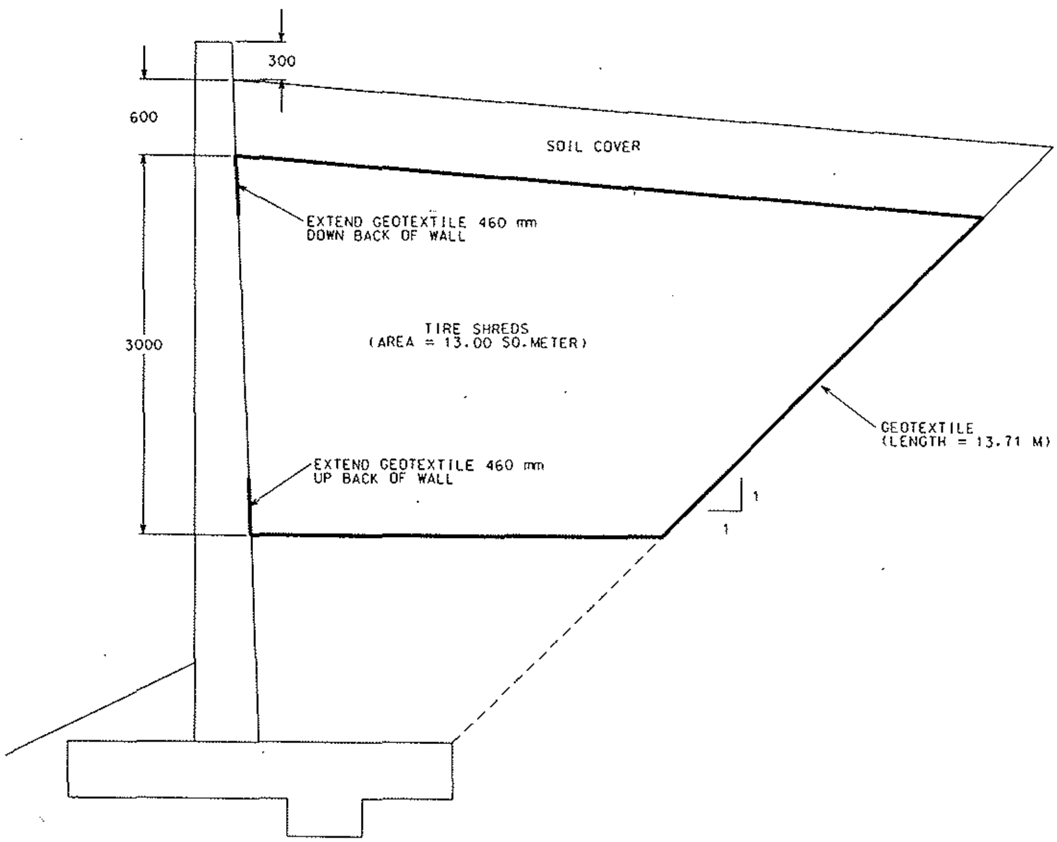

Figure VI-10. Typical section of Route 91 retaining wall

4. Construction photos are shown in Figures VI-11 through VI-13.

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VI-11. Unloading tire shreds from walking floor trailer.

Figure VI-12. Placement of tire shreds with tracked loader

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Figure VI-13. Compacting tire shreds with vibratory smooth drum roller.

E. Design of walls with tire shreds as backfill

1. Analysis is the same as for retaining walls with conventional backfill - overturning, sliding, bearing capacity

   a) Cantilevered retaining wall

   b) Gravity retaining wall

   c) Pile supported retaining wall

2. Settlement of underlying soils will be reduced because of lightweight tire shreds

F. Important design details

1. Geotextile should be used to separate the tire shreds from the surrounding soil; critical detail is junction of geotextile with back of wall – make sure you have a "leak free" contact at this location-- design with "belt and suspenders"

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VII. TIRE SHREDS AS INSULATION TO LIMIT FROST PENETRATION

A. Case history - Richmond, Maine

1. Located on dead-end town road in Richmond, Maine; serves 29 residences and two farms; traffic is cars, light trucks, and school buses; one day per month, 10 to 40 fully loaded double- and triple-axle dump trucks haul sewage sludge to the two farms (Humphrey and Eaton, 1992,1995; Eaton, et al., 1994)

2. During spring thaw the road becomes severely rutted even though existing road was surfaced with more than 18 in. of clean sandy gravel and gravely sand; subgrade soils ranged from gray silty clay to gray-brown silty gravely sand

3. Used tire shreds as thermal insulation to reduce depth of frost penetration - if subgrade soils don't freeze during the winter, they can't possibly be a problem thawing in the spring

4. Test site configuration

    a) Test site is 950 ft long and is broken up into five tire shred test sections; also one control section; two sections of existing road also used as control; plan and longitudinal views of test section are shown in Fig. VII-1

    b) Used two different thicknesses of tire shreds (6 and 12 in.); three different thicknesses of overlying soil cover (12, 18, and 24 in.); the top 4 in. of the soil cover was gravel with a maximum size of 1 in. so it would be easy for road crew to maintain road surface; configuration is summarized in Table VII-1

    c) In Section A, tire shreds were separated from surrounding soil with geotextile; in other sections, the tire shreds were in direct contact with the surrounding soil

    d) Typical cross section is shown in Fig. VII-2

5. Materials

    a) Tire shreds were uniformly graded and had a nominal maximum size of 2 in.; shreds were made from a mixture of steel and glass belted tires; used about 20,000 tires

    b) Gravel fill used over the tire shreds was well-graded mixture of sand and gravel with less than 5% passing the No. 200 sieve; in Section E, some of the gravel was materials excavated from the surface of the existing road

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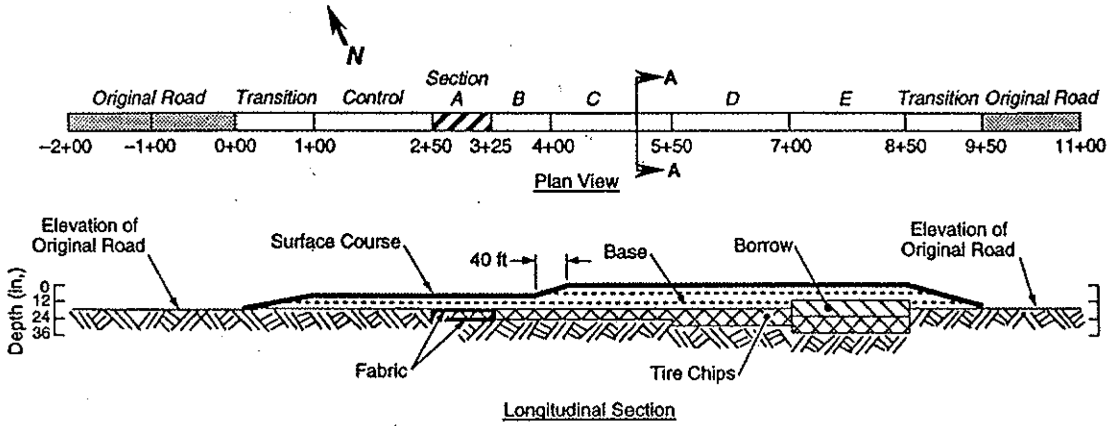

Fig. VII-1. Plan and longitudinal views of test sections of Richmond field trial

Table VII-1. Summary of test section configuration of Richmond field trial

Section	Depth of excavation (in.)	Thickness of layer (in .) Tire chips	Common borrow	Gravel fill	Surface course
Control	—	—	—	8	4
A	6	6	—	8	4
B	6	6	—	8	4
C	6	6	—	14	4
D	12	12	—	14	4
E	18	12	12	8	4

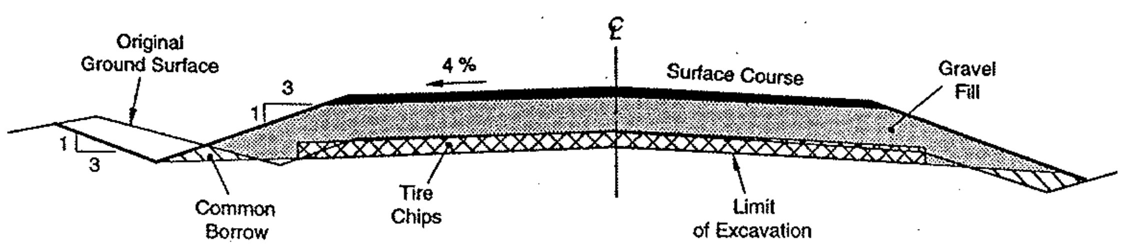

Fig. VII-2. Typical cross section of Richmond field trial

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6. Instrumentation

   a) Project was instrumented with the following: thermocouples and resistivity gauges to measure the depth of frost penetration; groundwater wells to measure the depth to the groundwater table and to obtain samples for water quality testing; benchmarks for heave surveys; weather station to monitor air temperature

   b) Instrumentation layout is shown in plan and longitudinal section in Figs. VII-3 and VII-4

7. Performance

   a) The freezing degree days were 1128°F-days in the winter of 1992-3 and 1273°F-days in 1993-4 (for comparison mean freezing index in central Nebraska is about 750°F-days)

   b) Maximum depth of frost penetration is summarized in Fig. VII-5

      (1) In control sections frost penetration ranged from 46 in. to 63 in.

      (2) In tire shred Sections A, B, D, and E depth of frost penetration ranged from 36 in. to 40 in.

      (3) In Section C penetration was 41 in. to 47 in. - greater than in Sections A and B; reason is that insulation is more effective when placed nearer road surface

   c) Frost penetration versus date for winter of 1993-4 is shown in Fig. VII-6

      (1) Frost penetrates very rapidly in first few weeks of freezing season

      (2) In control section frost depth increases throughout winter

      (3) In Sections A, B, and C rate of penetration greatly reduced by tire shreds

      (4) In Sections D and E negligible additional penetration after early January

   d) Comparing temperature above and below the tire shred layer also shows the effectiveness of tire shreds as shown in Fig. VII-7

   d) Frost heave was reduced by up to 25% in tire shreds sections as shown in Fig. VII-8

7. A similar project on an unpaved road was constructed in Vermont (Frascoia,1991, 1994; Frascoia and Cauley, 1995); reported improved performance

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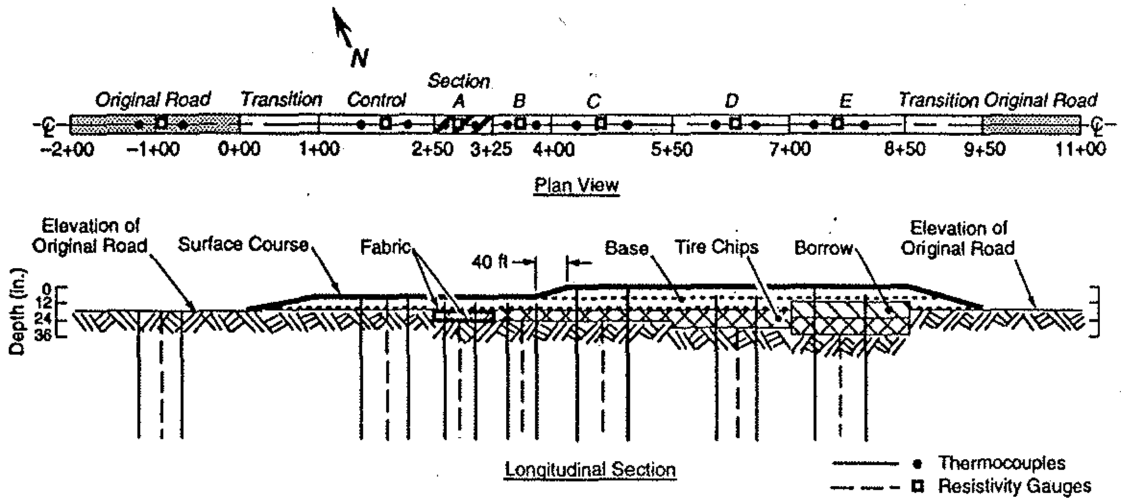

Fig. VII-3. Location of thermocouples and resistivity gauges.

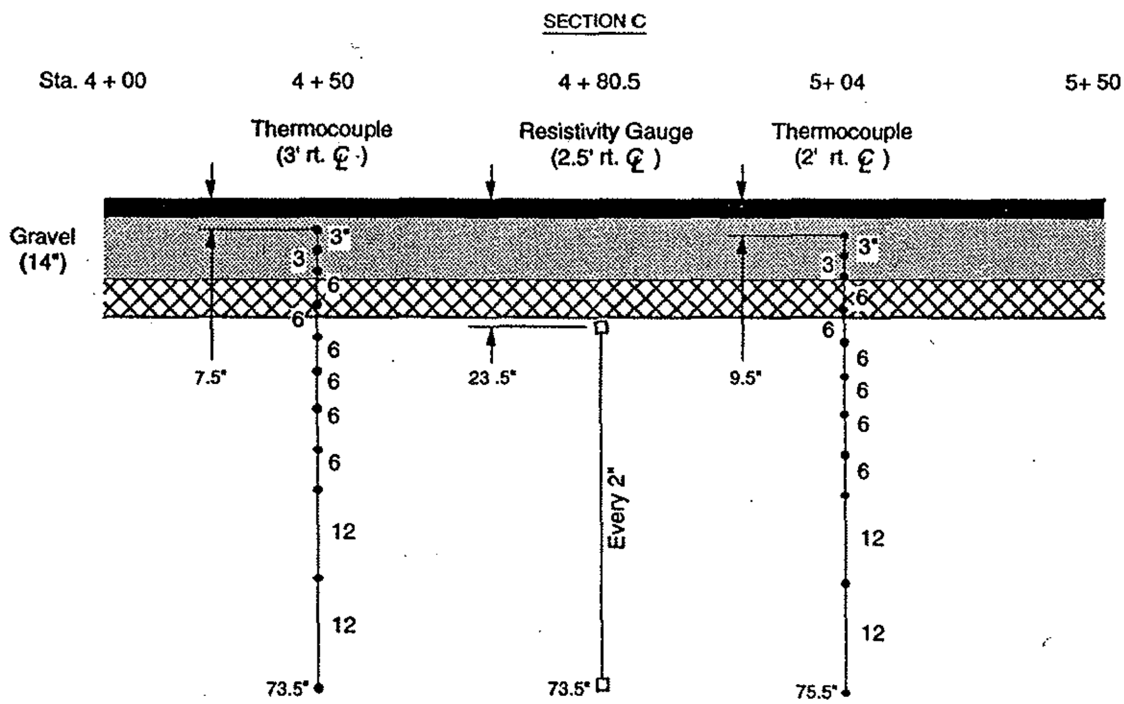

Fig. VII-4. Longitudinal section showing thermocouples and resistivity gauges in Section C

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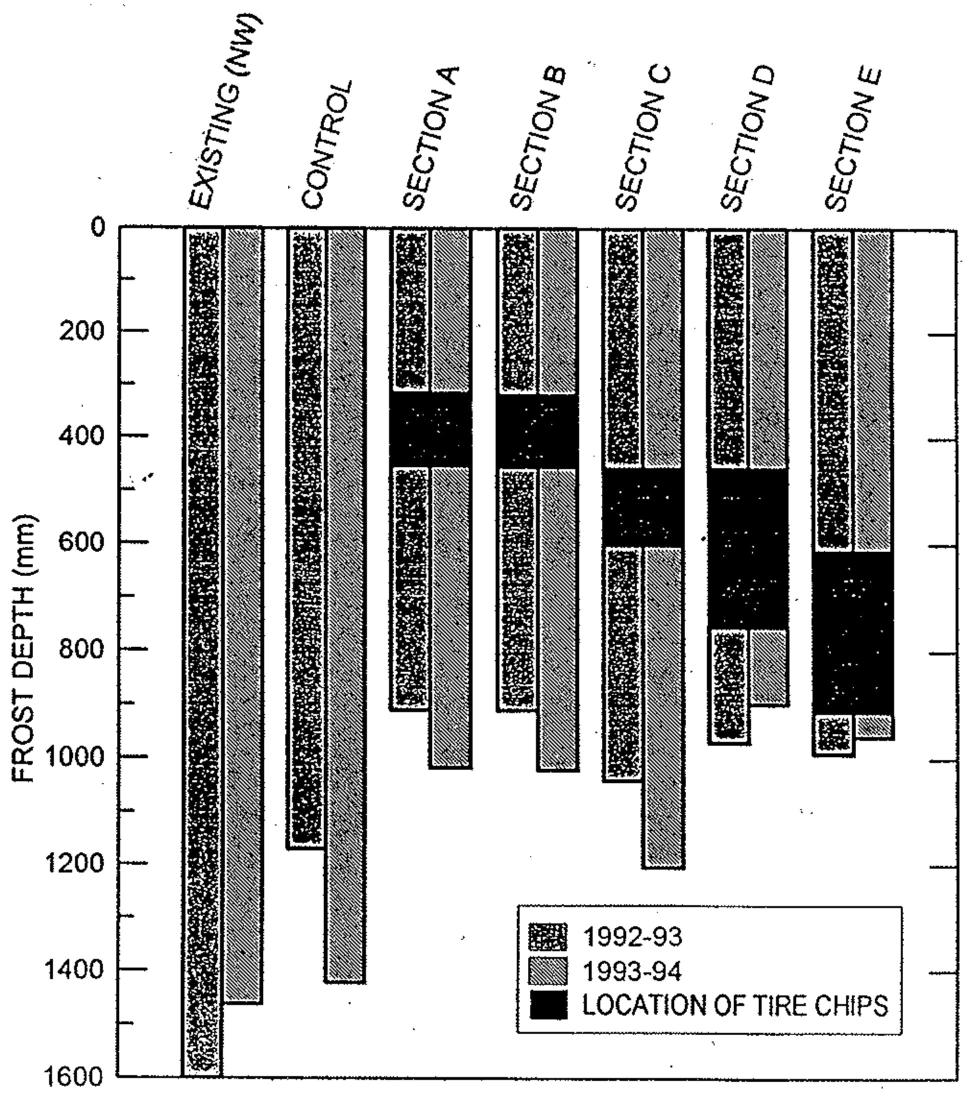

Fig. VII-5. Maximum depth of frost penetration (Humphrey and Eaton, 1995)

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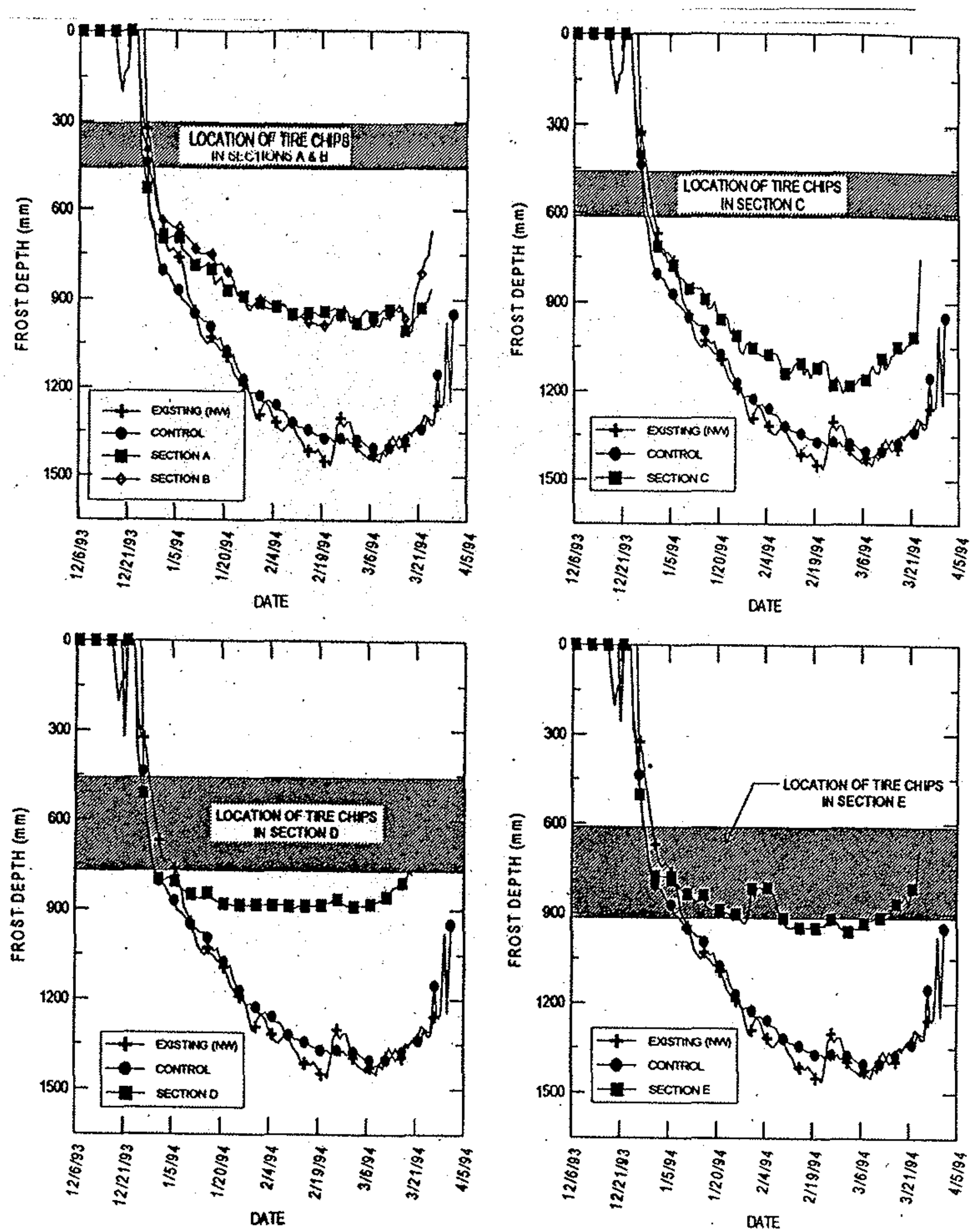

Fig. VII-6. Depth of frost penetration versus date - winter of 1993-4 (Humphrey and Eaton, 1995)

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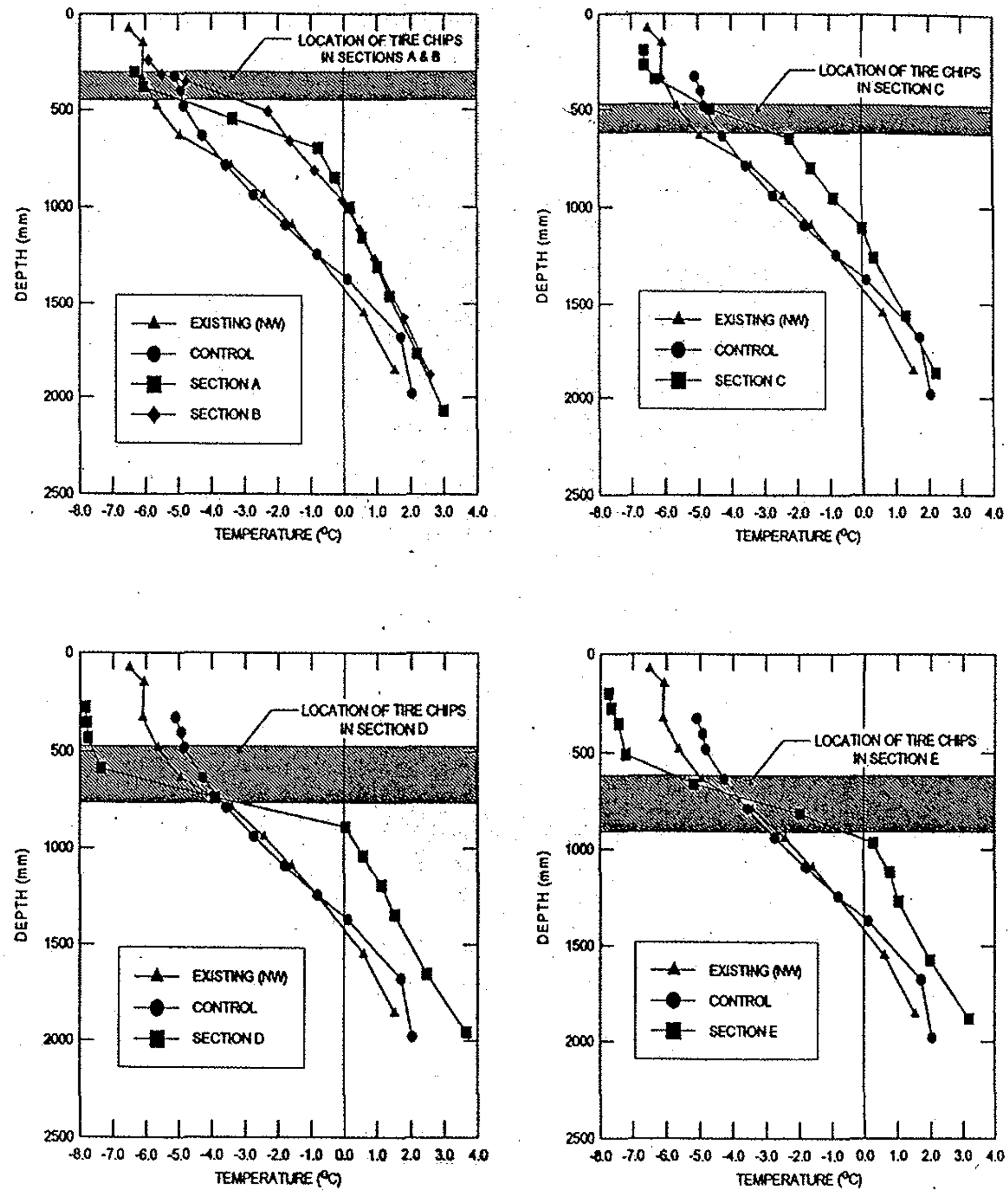

Fig. VII-7. Temperature profile on February 16, 1994 (Humphrey and Eaton, 1995).

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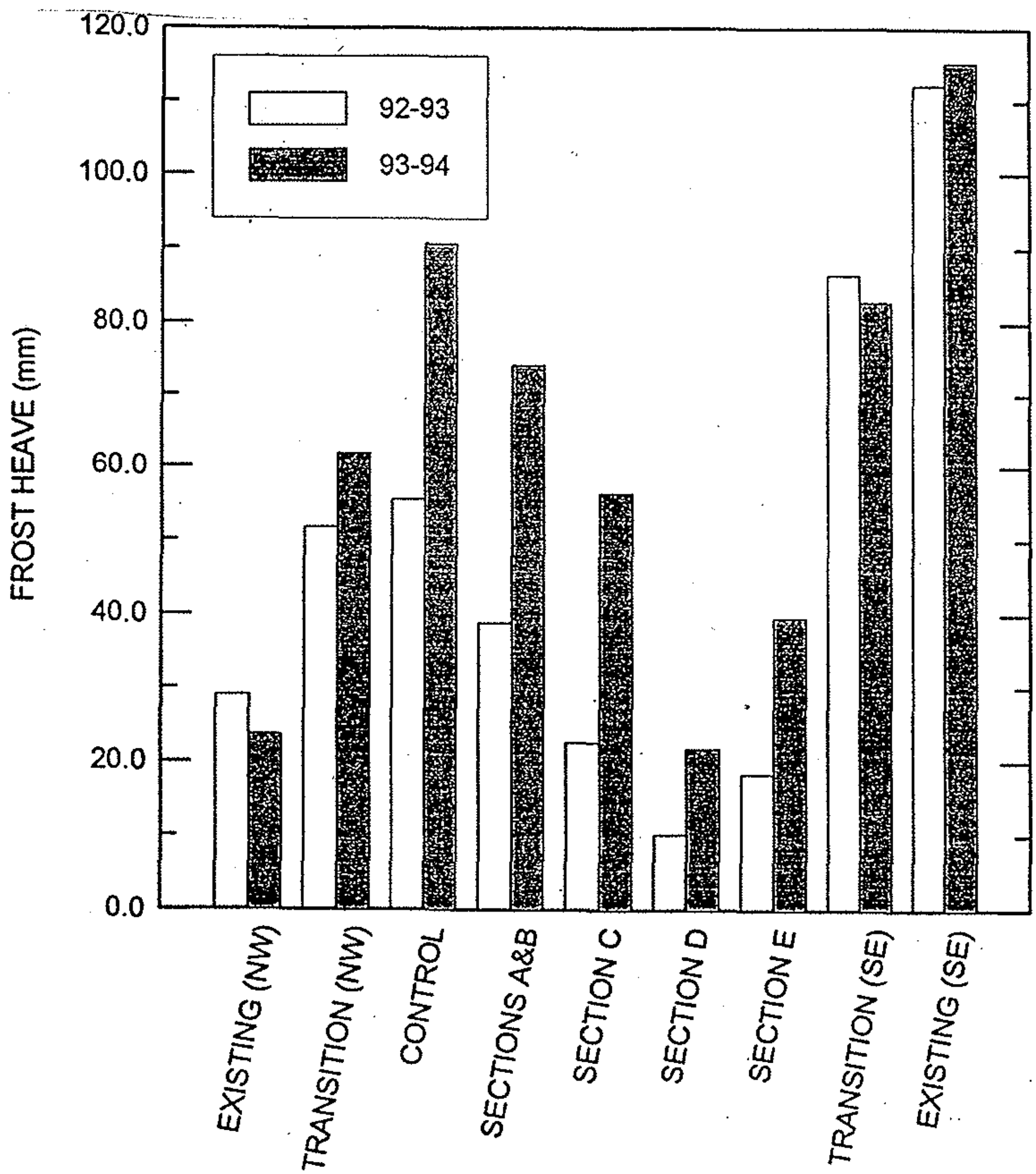

Fig. VII-8. Measured frost heave (Humphrey and Eaton, 1995)

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B. Case history – NETC test road

1. Constructed field trial to investigate use of tire shreds to reduce frost penetration and improve drainage beneath paved roads. (Lawrence, et al., 1998)

2. Soil cover varied from 13 in. to 19 in. Used tire chips with 3-in. maximum size, as well as mixtures of 33% tire shreds/67% soil and 67% tire shreds/33% soil. A control section was built using 25 in. of subbase aggregate over the subgrade soils. An underdrain was incorporated along one shoulder of the road. A pavement thickness of 5 in. was used in all the sections. A longitudinal section is shown in Fig. VII-9 and a typical cross section is shown in Fig. VII-10.

3. Frost penetration

    a) Frost penetration versus date is shown in Fig. VII-11; in the sections with 100% tire shreds (Sections 3, 4, and 5) it is seen that the frost penetration remained in the tire shred layer or penetrated only a short depth into the subgrade soil; in contrast, Section 1, which had 33% shreds/67% soil showed very similar behavior to the control section indicating that there is little benefit to using this mixture as subgrade insulation

    b) The maximum depth of frost penetration is summarized in Fig. VII-12. Results clearly show that tire shreds reduced the depth of frost penetration.

4. Frost heave

    a) Frost heave was measured at sixteen points in each section; average heave in each of the wheel paths is shown in Fig. VII-13

    b) For most of the sections less heave occurred in the two inner wheel paths compared to the two outer wheel paths. A possible explanation is that the soil beneath the outer wheel paths had greater access to water and some cold penetrated beyond the edge of the tire shred layer

    c) Examining the two inner wheel paths, it is seen that the heave in Sections 3 and 5, which had 12 in. of tire shreds, was very small compared to the control section. This shows that tire shred insulating layers are very effective in controlling frost heave

5. Backcalculated thermal conductivity

    a) The backcalculated thermal conductivity of tire shreds ranged from 0.16 to 0.18 W/m·°C (0.09 to 0.10 Btu/hr·ft·°F); these are lower than the laboratory values determined in the NETC study, but are similar to values backcalculated from the Richmond Field Trial

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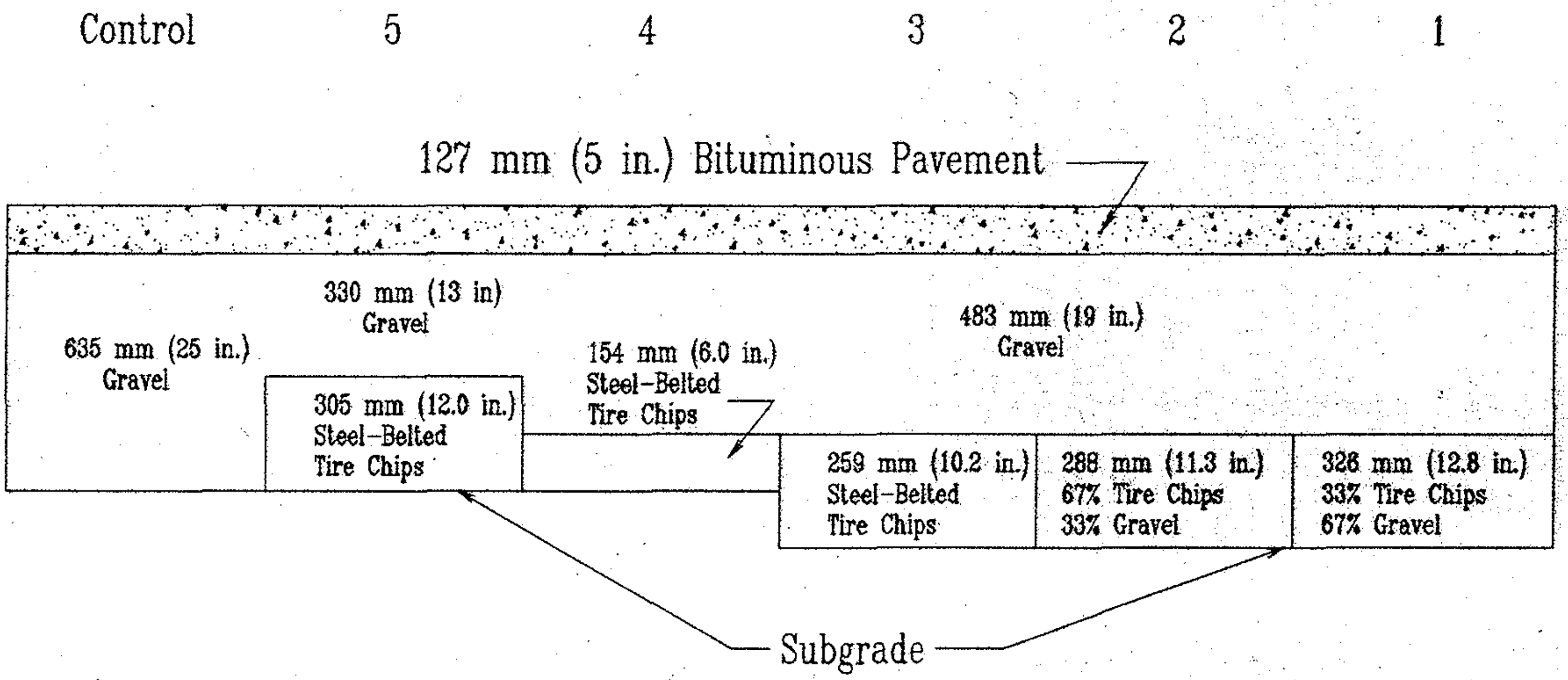

Fig. VII-9. Longitudinal section along centerline of road (Lawrence, et al., 1998).

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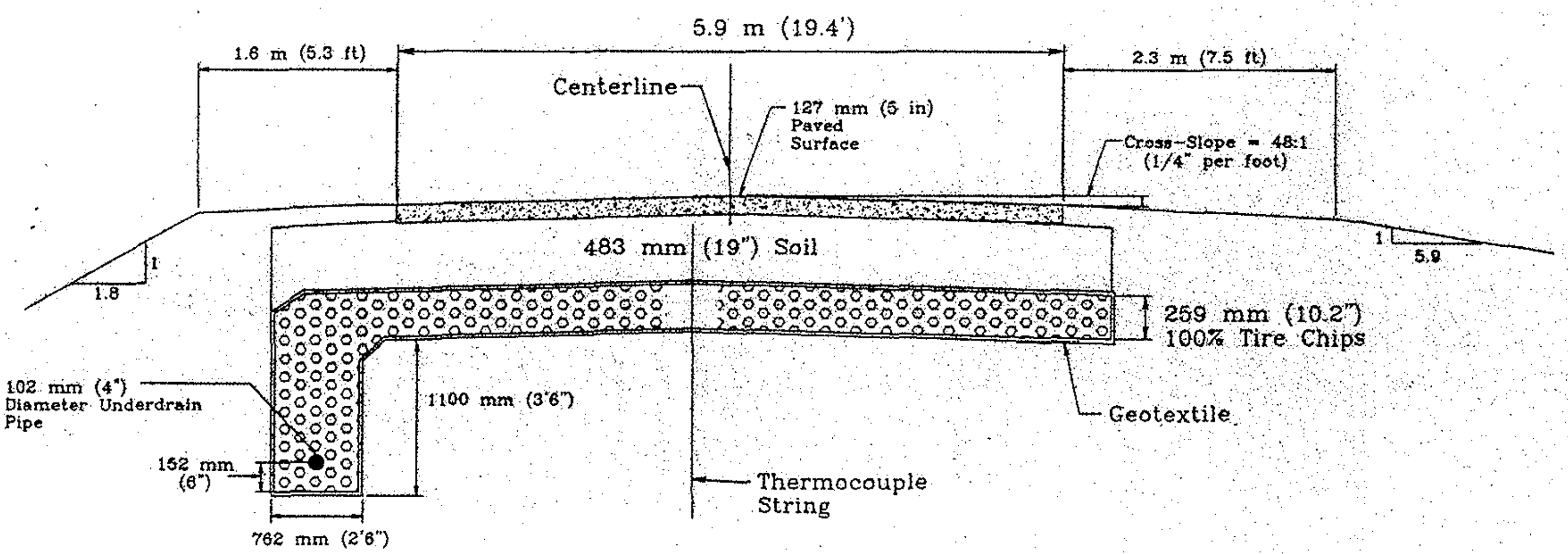

Fig. VII-10. Cross section of Section 3 (Lawrence, et al., 1998).

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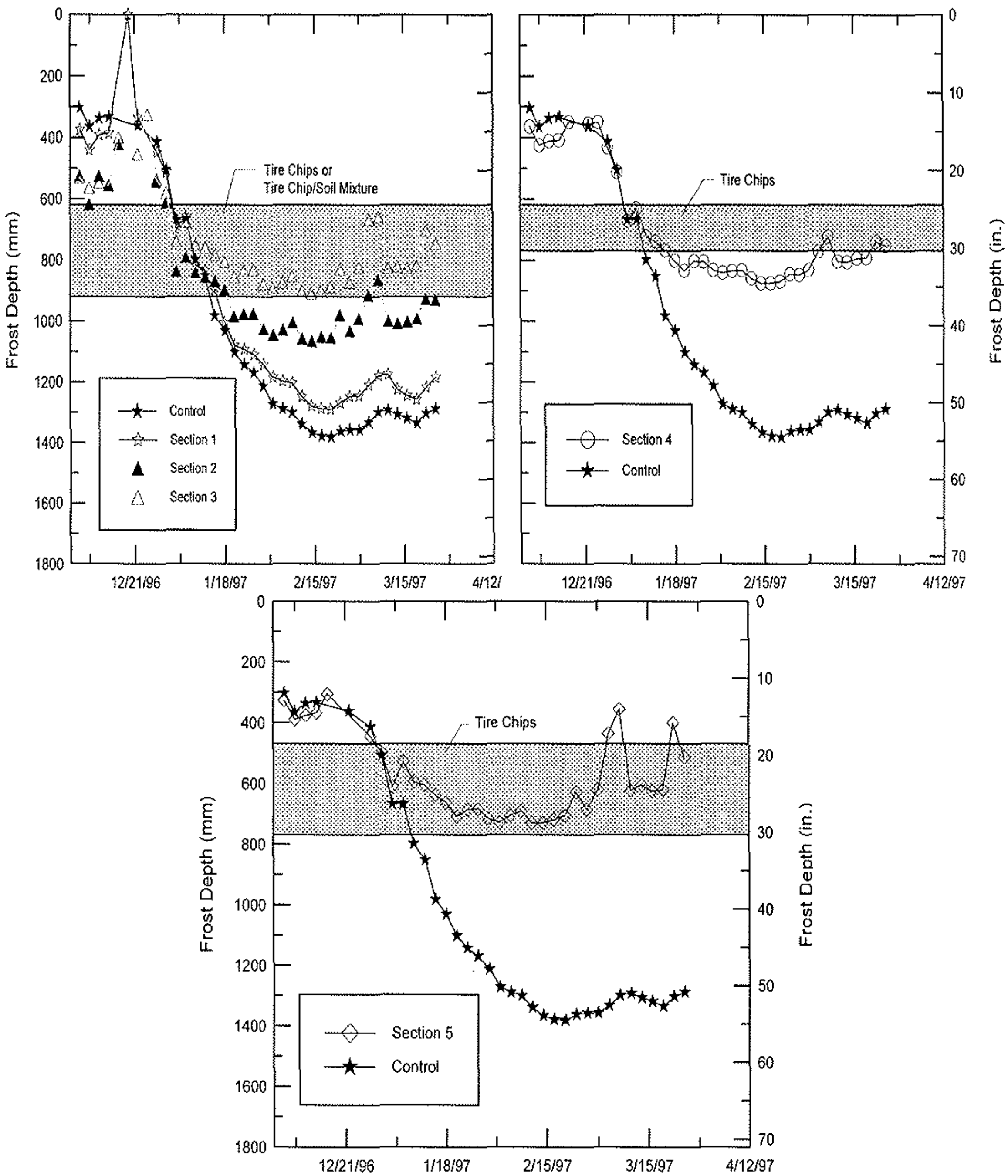

Fig. VII-11. Frost penetration versus date for NETC test road (Lawrence, et al., 1998).

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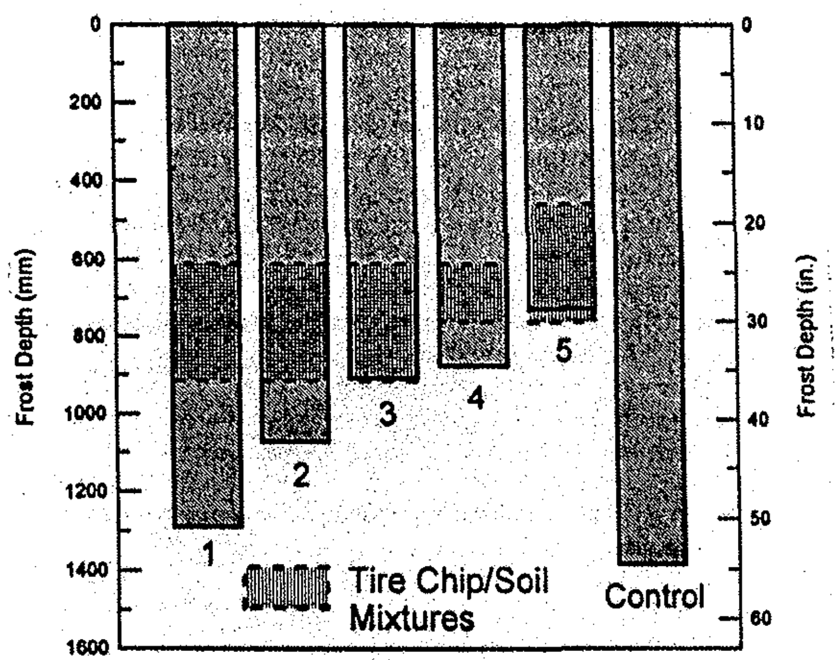

Fig. VII-12. Maximum depth of frost penetration for winter of 1996/7 in the NETC test road. (Lawrence, et al., 1998)

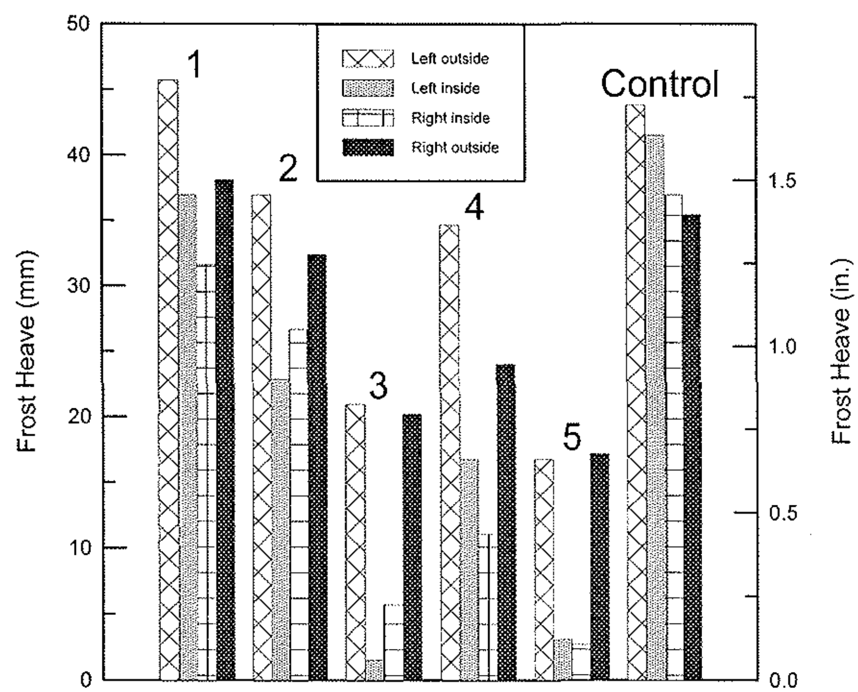

Fig. VII-13. Average frost heave in individual wheel paths in the NETC test road.

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C. Design of tire shred insulating layers

1. Depth of frost penetration
    a) Need to know freezing index at project location
    b) Estimate thermal properties of pavement, soil cover, tire shreds, and subgrade soil; see tire shred properties section of notes for thermal conductivity of tire shreds
    c) The thermal properties of tire shreds given in Section IV.J would give a conservative (i.e., slightly high) estimate of the thermal conductivity of tire shreds with a maximum size of 3 in.
    d) Chose thickness of tire shreds and soil cover
    e) Calculate depth of frost penetration
    f) Calculation method given in Aldrich (1956), "Frost Penetration Below Highway and Airfield Pavements," *Highway Research Board Bulletin 135*, National Research Council, Washington, D.C., pp. 124-144.
2. In addition to cutting off penetration of freezing temperatures into the ground, insulation reduces heat flow to pavement surface; if insulation is too close to pavement, the section will ice up much sooner than an uninsulated section; to prevent this recommend minimum of 20 in. of soil between top of tire shred insulating layer and bottom of pavement
3. Tire shreds also have potential as insulating backfill around building foundations to limit heat loss and to prevent underdrains from freezing.

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VIII. TIRE SHREDS FOR LATERAL EDGE DRAINS

A. Case history – NETC Test Road

1. Tire shreds and tire shred/soil mixtures were used as an edge drain in the NETC Test Road as shown in Fig. VII-10.

2. Thermocouples were not installed so it could not be determined if the drain remained above freezing during the entire winter. However, frost penetrations measured at the center of the road show suggest that frost penetrated to the top of the underdrain pipe in the section with subbase aggregate backfill while the sections with tire shred backfill probably remained frost free

3. No distress was noted in the pavement adjacent to the edge of the drain, moreover, pavement deflections adjacent to the drain measured in April were lower than values measured at distances greater than 6 ft from the drain; this suggests that the compressibility of the shreds in the drain did not adversely affect pavement performance and that the tire shreds were providing beneficial drainage.

B. Case history – Route 201, Moscow, Maine

1. Tire shreds were used to insulate an underdrain pipe and a seepage collector pipe as part of reconstruction of Route 201 in Moscow, Maine. In both locations the shreds extended about 1 ft above the top of the pipe

2. In the section with the underdrain pipe, the tire shreds kept the pipe above freezing for the entire winter while the pipe in an adjacent control section was below freezing in the latter part of the winter.

3. The seepage collector pipe was connected to weep holes located at the toe of a soil nail wall. During the winter, the snowbank over the pipe location reached a thickness of 8 to 10 ft. The insulating value of the snow kept both the section of pipe bedded in tire shreds and the control section bedded in aggregate well above freezing for the entire winter.

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IX TIRE SHREDS AS VIBRATION DAMPING LAYER BENEATH RAIL LINES

A. Case history – VTA Maintenance Yard Test Section

1. A trial of tire shreds as a vibration damping layer was constructed in the Valley Transit Authority (VTA) maintenance yard in San Jose, CA. The trial as a joint effort between the California Integraged Waste Management Board, the Valley Transit Authority, Korve Engineering, Wilson, Ihrig & Associates, and Dr. Dana N. Humphrey. The purpose of the tire shred layer is to reduce ground bourn vibrations that would affect residences and businesses located adjacent to transit lines.

2. The cross section consisted of 12 in. of Type A tire shreds, 12 in. of subballast, and 12 in. of ballast as shown in Figure IX-1. The tire shreds were wrapped in geotextile. Continuous welded rails were attached to concrete ties. There was a control section with 8 in. of subballast and 8 in. of ballast.

3. Placement of the tire shreds is shown in Figure IX-2. The completed test section is shown in Figure IX-3.

4. The rails were instrumented with strain gages attached to the rail head and base as shown in Figures IX-4 and IX-5. In addition, dial gages with an accuracy of 0.001 in. were used to measure tie deflections as shown in Figure IX-4.

5. The test and control sections were loaded with the light rail vehicle shown in Figure IX-6. The vehicle applied the following loads: east motor truck – 42,000 lb; center truck – 35,640 lb; and west motor truck 41, 000 lb.

6. The tire shred section showed strains that were less than 10 microstrains higher than the control section as shown in Figures IX-7 and IX-8. The strains due to temperature changes during the course of the one-day test were larger than those caused by LRV loading. The increase in strains caused by the tire shreds would have little effect on rail performance.

7. Elastic deflections of the ties were less than 0.2 in. as shown in Figure IX-9. However, there was some permanent deflection of the ties which may necessitate more frequent releveling of the ties.

8. Vibrations in the test and control section were monitored with vibration transducers shown in Figure IX-10. The tire shreds resulted in significant reductions in vibrations as shown in Figure IX-11.

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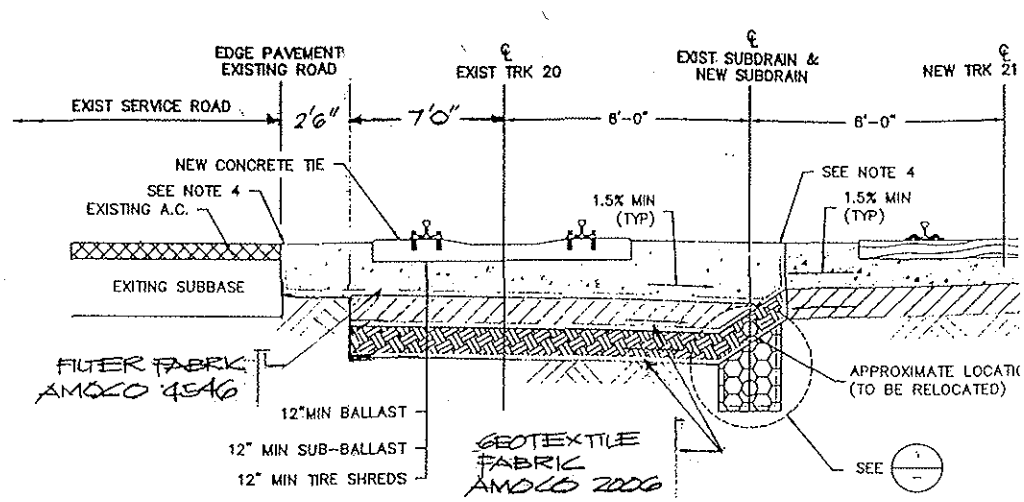

Figure IX-1. Cross section of tire shred test section.

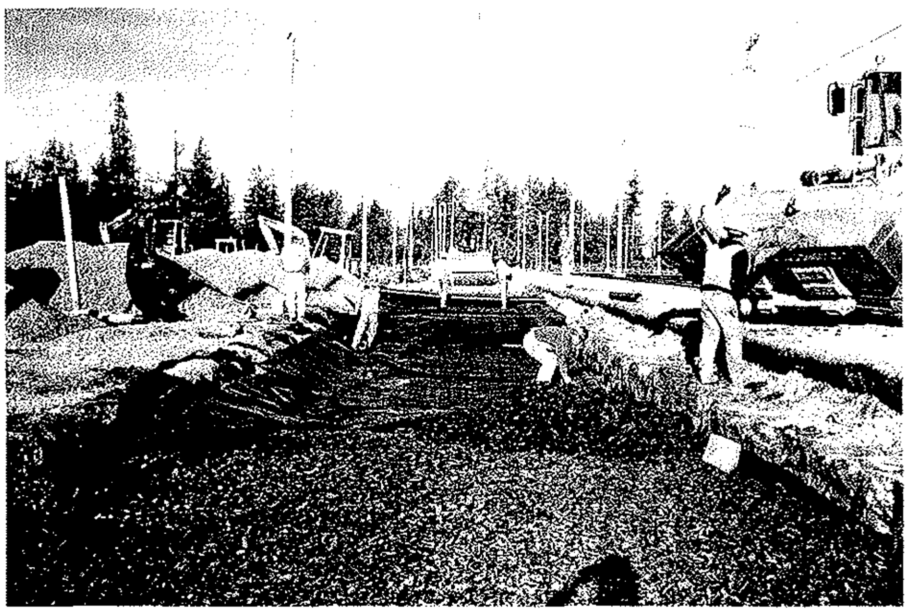

Figure IX-2. Placement of tire shreds (photo courtesy of IT Corp).

Figure IX-3. Finished test track (photo courtesy of Wilson, Ihrig & Assoc.)

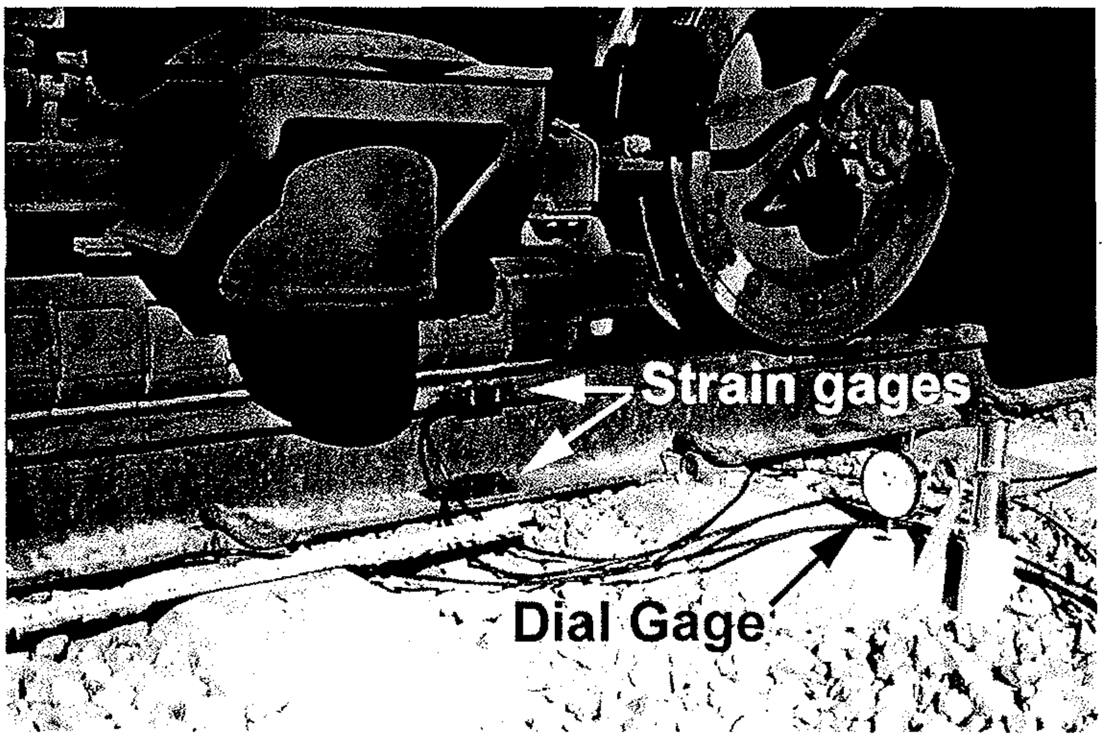

Figure IX-4. Instrumentation.

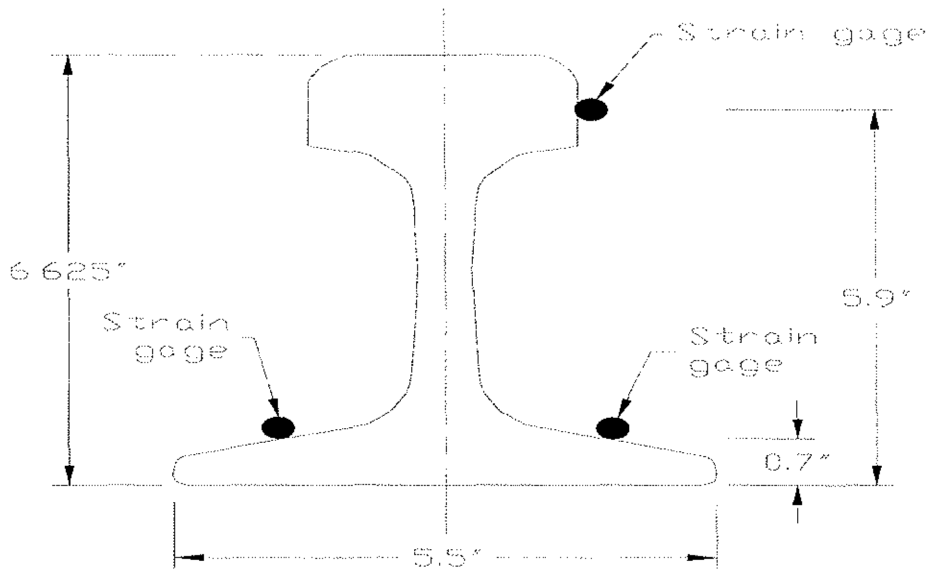

Figure IX-5. Location of strain gages.

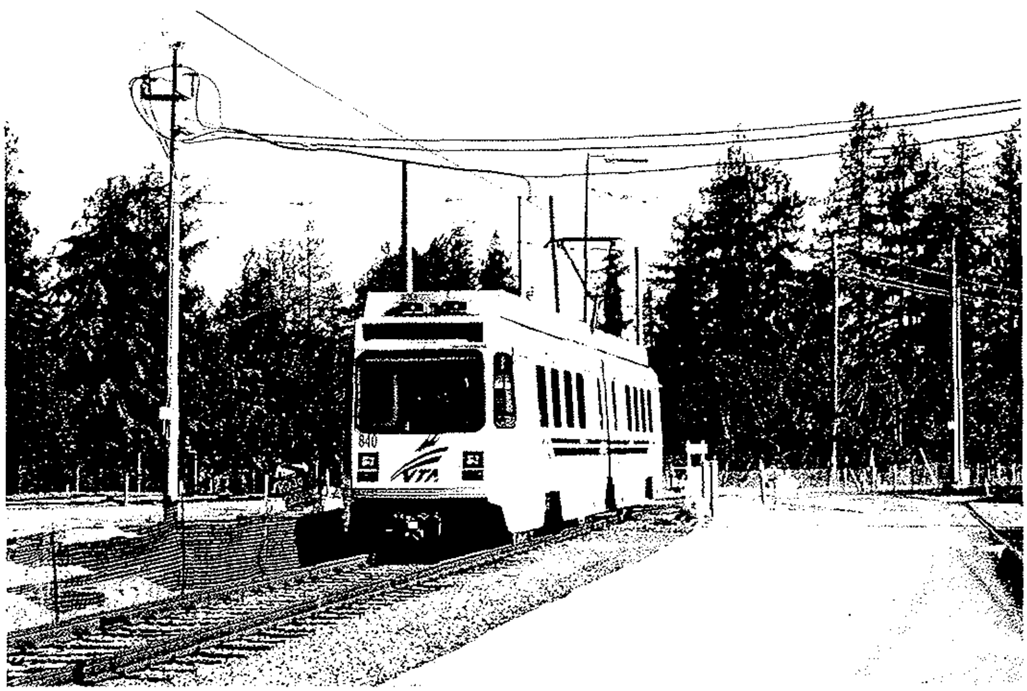

Figure IX-6. Test train - VTA light rail vehicle #840 (courtesy of Wilson, Ihrig & Associates).

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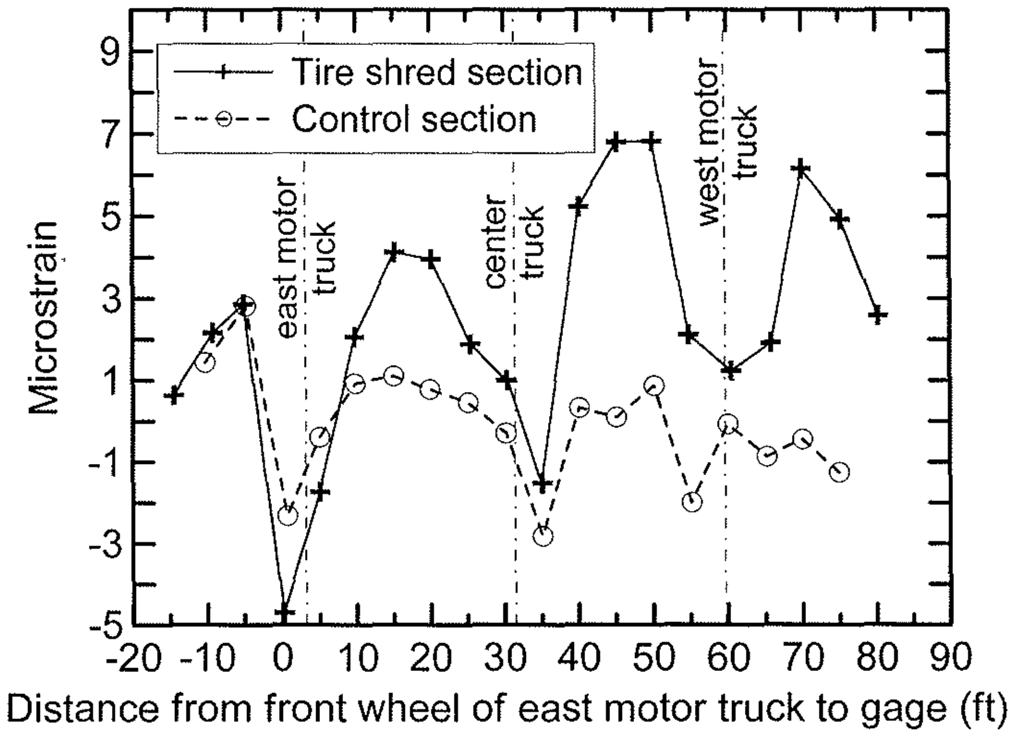

Figure IX-7. Strain in rail base.

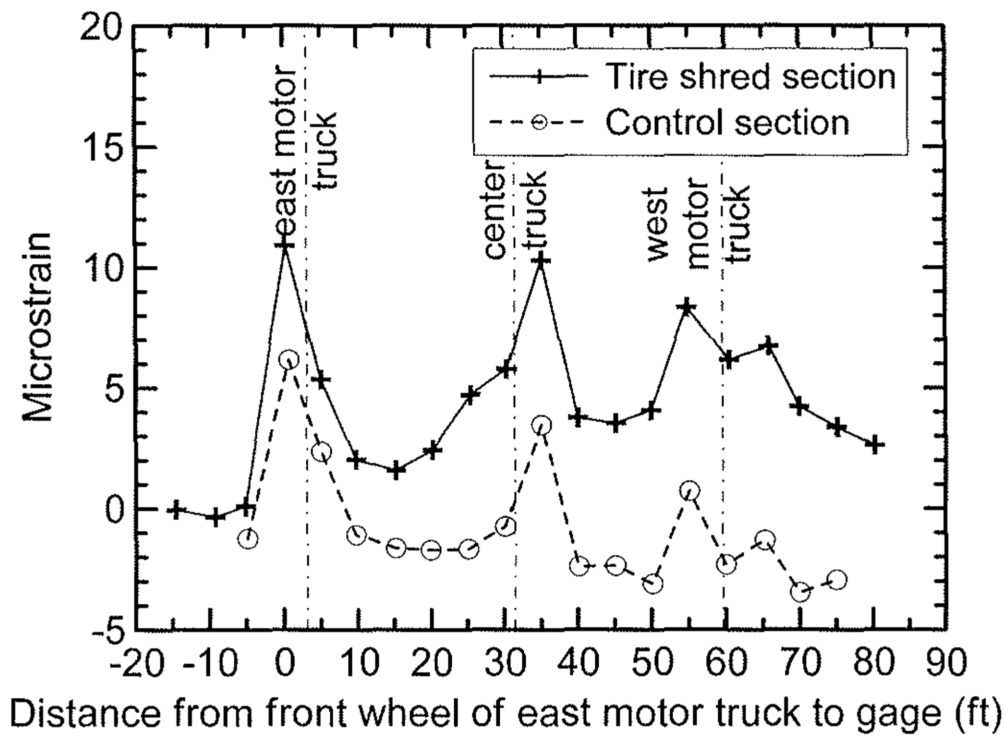

Figure IX-8. Strain in rail head.

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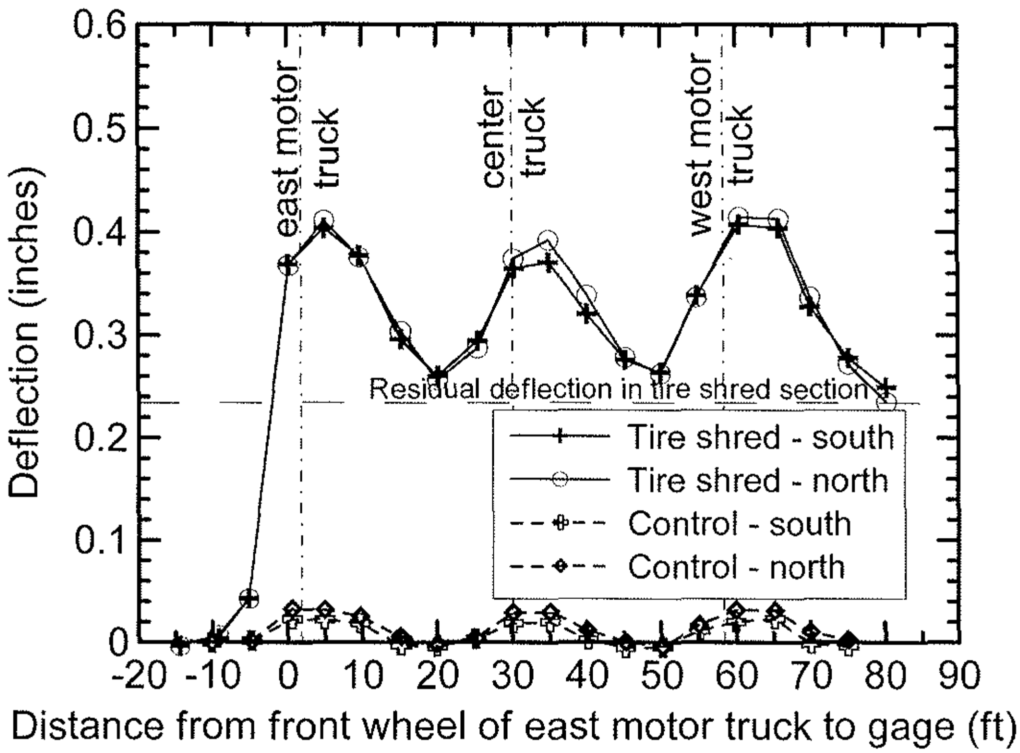

Figure IX-9. Tie deflection.

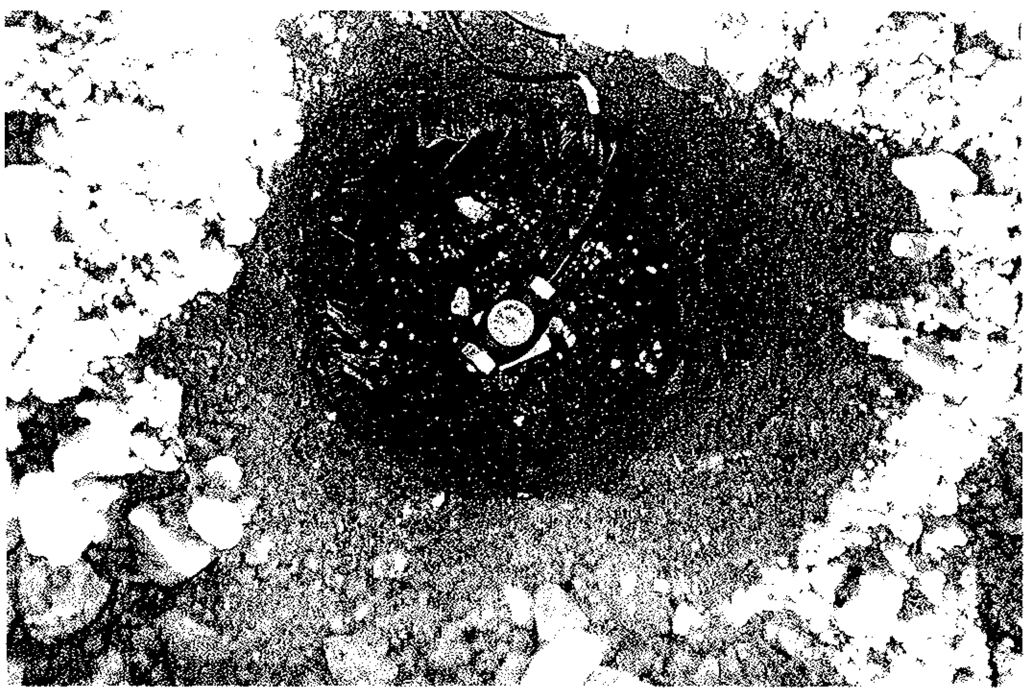

Figure IX-10. Vibration transducer mounted on spike embedded in ground (photo courtesy of Wilson, Ihrig & Associates).

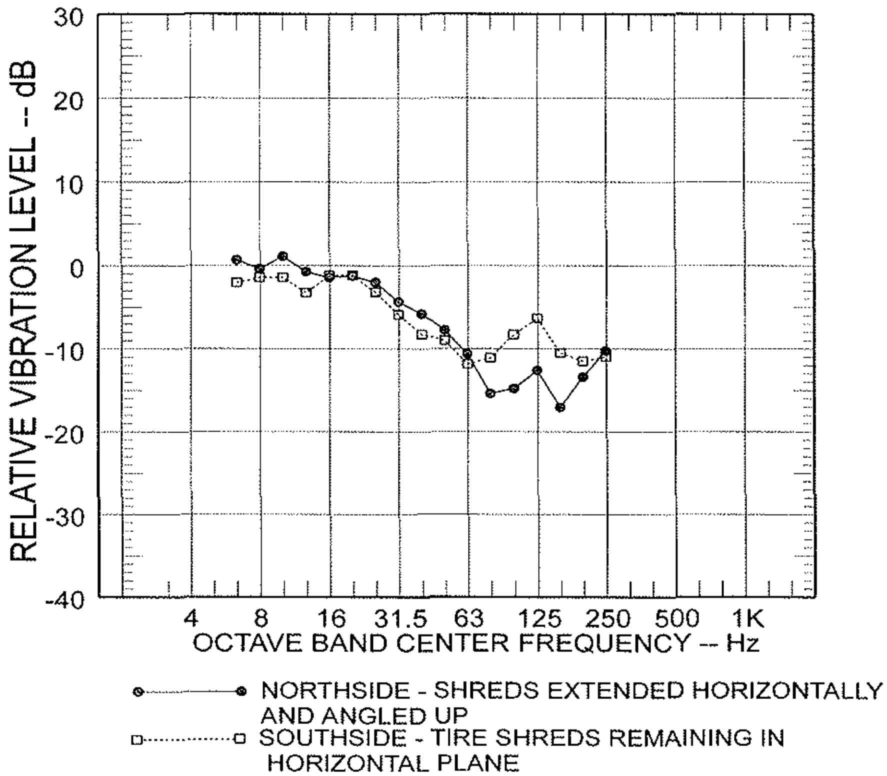

Figure IX-11. Average attenuation of VTA tire shred test area; train operations on both directions, all measurement distances.

B. Case history – Vasona Light Rail Project, San Jose, CA

1. Based on the favorable results of the VTA maintenance yard test section, the VTA chose to use tire shreds as a vibration mitigation method for the Vasona Light Rail Project which is currently under construction.

2. The cross section is similar to that used in the maintenance yard test section as shown in Figure IX-12.

3. Vibration mitigation was needed on several section of the corridor because of the close proximity of residences and businesses as shown in Figure IX-13. Tire shreds are specified for 1591 ft (485 m) of track.

4. Construction of the initial tire shred section is shown in Figures IX-14 and IX-15.

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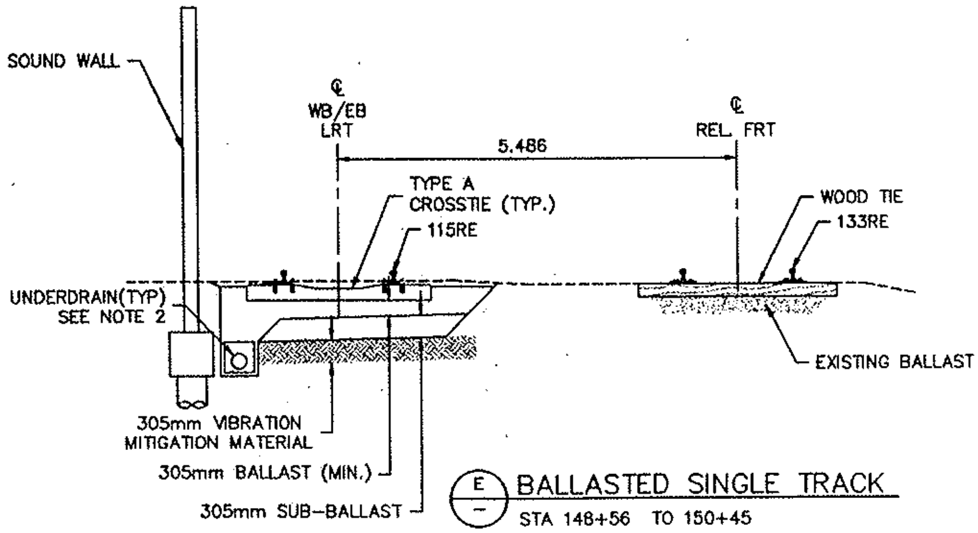

Figure IX-12. Typical cross section of Vasona Light Rail Project (Korve Engineering, 2001).

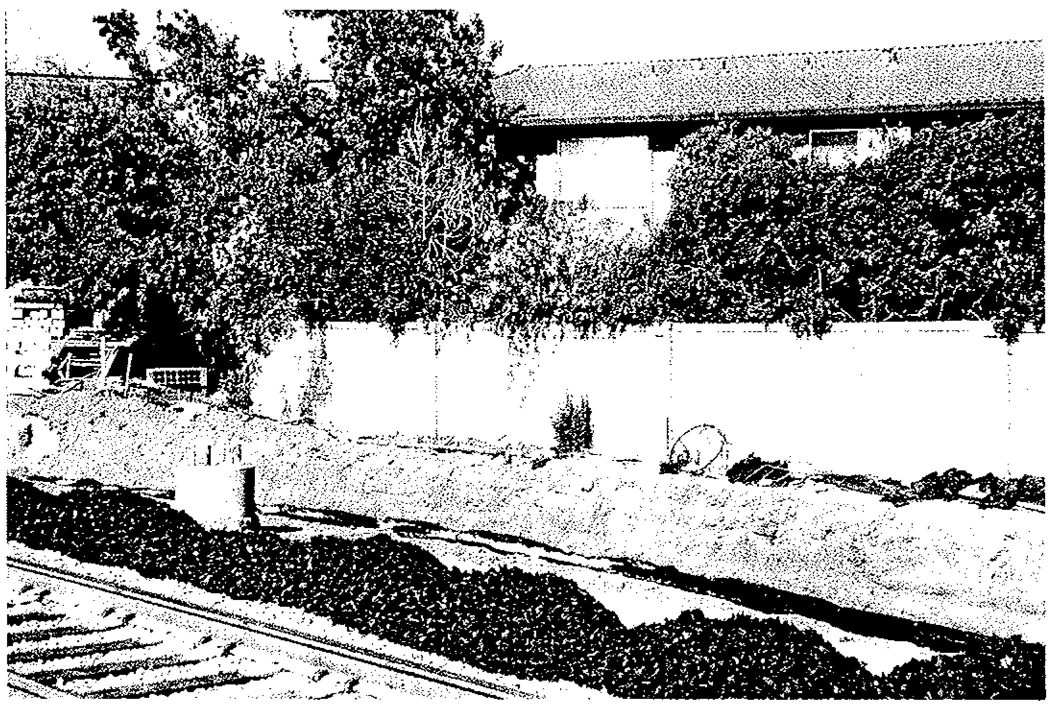

Figure IX-13. Proximity of residences to the rail corridor.

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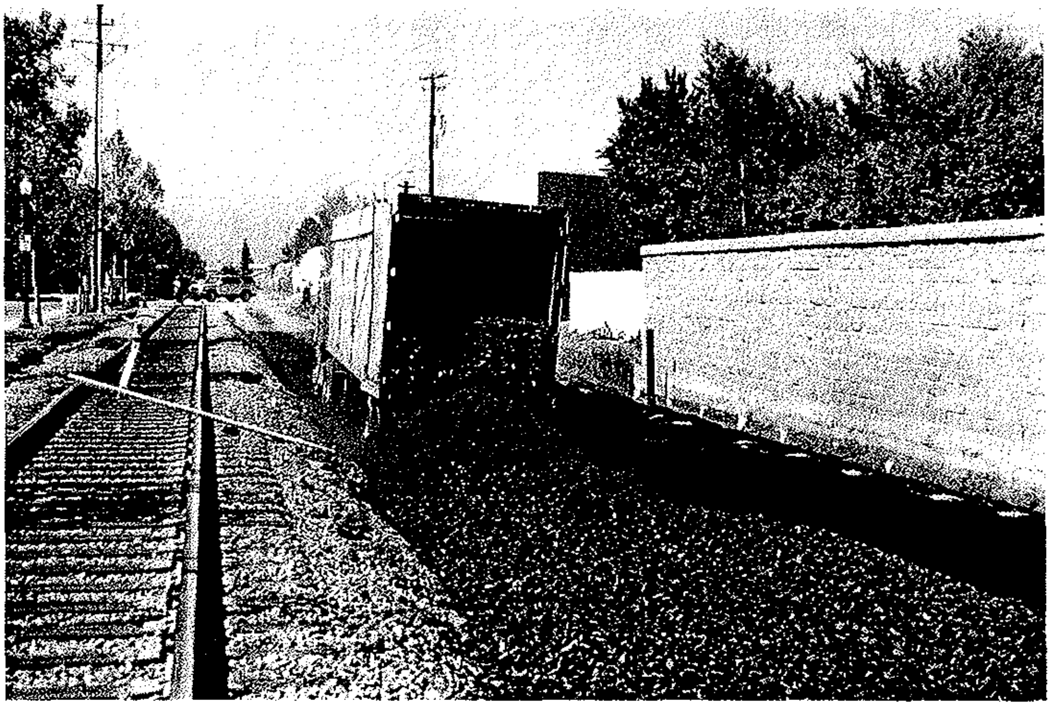

Figure IX-14. Unloading tire shreds.

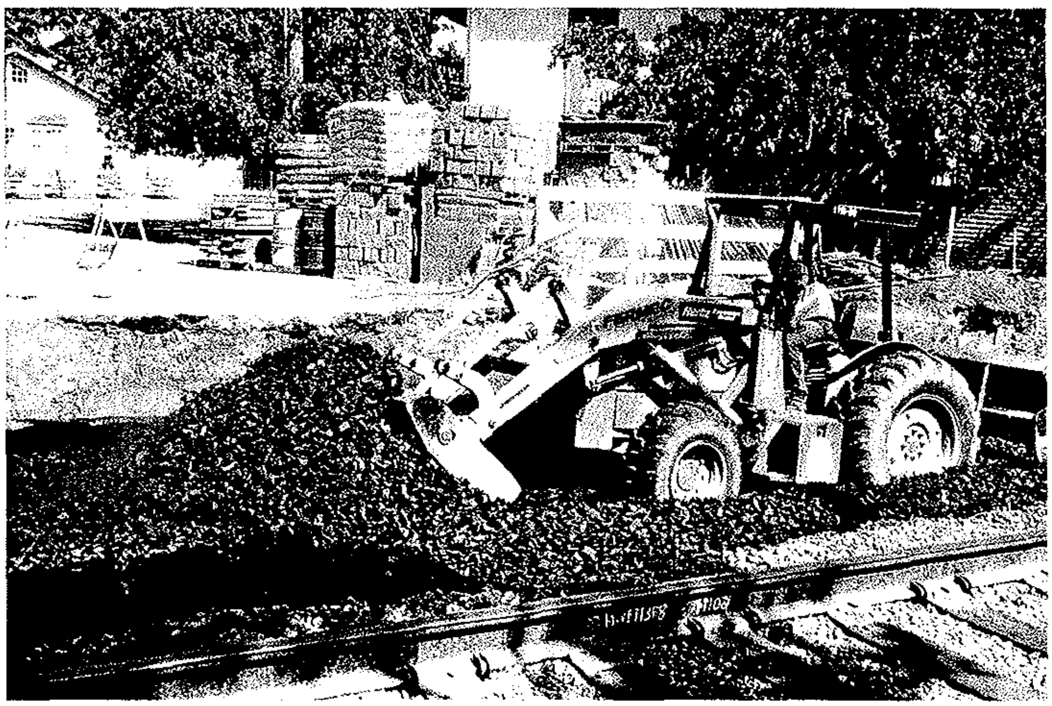

Figure IX-15. Spreading tire shreds.

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X. USE OF TIRE SHREDS IN LANDFILLS

A. Introduction

1. Use as drainage layer in landfill liner, landfill cap, gas collection layer, or daily cover

2. In addition to providing drainage, the tire shred layer may limit freezing of underlying clay barriers; freezing increases the permeability of clay barriers, in some cases up to two orders of magnitude

B. Drainage layer in leachate collection system

1. In this application the tire shreds are a component of the leachate collection system; in some cases their main function is to protect the liner system from damage during construction and operation

2. Tire shred size - generally use shreds with a maximum size of 3-in.; a landfill recently constructed in Maine used shreds with a maximum size of 12-in. and a nominal (mean) size of about 6 in.

3. Select permeability of tire shreds from your test data or from typical values given previously; remember that tire shreds are compressible so permeability decreases as the overburden pressure increases; use overburden pressure due to weight of overlying waste

4. Tire shreds are compressible so the thickness of the layer that is placed needs to account for the decrease in the thickness of the layer under the weight of the overlying waste

5. Calculate capacity of drain using the same analytical techniques you'd use for soil

6. Tire shreds should not be placed directly on a geomembrane liner because of the possibility that steel belts protruding from the cut edges of the tire shreds could puncture the liner when subjected to the weight of the overlying waste; place 12 in. of granular soil over the liner as a protective layer

7. If tire shreds placed on a clay liner, you probably want to use a geotextile as a separator between the clay and the shreds; this will minimize the amount of fines that will get washed into the tire shred layer over time

8. Should not put waste with a high fines content directly on top of the tire shred layer to minimize the potential that fines from the waste would wash into the tire shred layer

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9. Case histories

   a. Quarry Landfill and Recycling Center, Oklahoma (Oklahoma Dept. of Health, 1993)

      (1) Tire shreds placed on granular cushion over geomembrane

   b. Muskogee Community Landfill, Oklahoma (Donovan, et al., 1996)

      (1) Tire shreds placed on granular cushion over geomembrane

   c. North Texas Municipal Water District Landfill, Texas (Scrap Tire News, 1995)

      (1) Tire shreds placed directly on thick compacted clay liner

   d. Souix City Landfill, Iowa (HDR Engineering, 1994)

   e. East Oak Landfill, Oklahoma (Rust Environment, 1994)

      (1) Tire shreds used as a protective layer over the liner system

   f. Newland Park Landfill, Wicomico County, Maryland

   g. Lewiston Landfill, New York; operated by Modern Landfill, Inc. (Goehrig, 1996)

C. Leachate recirculation trenches

1. Leachate recirculation trenches are used to reintroduce collected leachate back into the waste; granular soil is conventionally used (Donovan, et al., 1996)

2. Compressibility of tire shreds is not a problem as it is comparable to the surrounding waste

3. Has been used in this application in Alachua County Southwest Landfill, Florida (Townsend, et al., 1995)

D. Drainage layers in landfill covers

1. The comments given above for landfill liners regarding permeability and layer thickness also apply to drainage layers in landfill covers; however, the stresses will be due only to the weight of the overlying vegetative support layer; drain capacity calculated using the same methods used for soils

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2. Tire shreds must be completely enclosed in geotextile to minimize the amount of fines that will flow into large pores between tire shreds decreasing its permeability

3. In some cases the tire shreds have been placed directly on top of a geomembrane layer; if this is done the amount of steel belts exposed at the cut edges of the tire shreds must be minimized

4. If tire shred drainage layer is on a sloped geomembrane, you need to check slope stability; probably need to use a textured geomembrane to increase friction angle of interface

5. Case histories

    a. DSI Superfund Site, Vermont; tire shreds used in drainage layer placed directly on 60-mil Very Low Density Polyethylene geomembrane

E. Gas Collection Layer

1. Probably not a good idea to place a geomembrane liner directly on the tire shred layer unless care is taken to minimize the amount of steel belt exposed at the cut edge of the tire shreds

2. Should consider how the compressibility of the tire shred layer would affect the integrity of the overlying compacted clay barrier or geomembrane barrier; most important during construction

3. A test pad recently constructed in California showed that a 1-ft thick clay layer compacted over tire shreds contained numerous cracks that would likely increase the permeability of this layer; a second 1-ft thick lift of compacted clay was constructed on the first layer; the second layer contained fewer cracks but cracking was still noticeable.

F. Gas control trenches

1. Located beyond the footprint of the landfill to control lateral migration of landfill gas; generally these are trenches filled with granular soil (Donovan, et al., 1996)

2. Tire shreds used in this application in the North County Landfill Incinerator, Kansas; no geotextile or other filter material was used between the tire shreds and the surrounding soil

G. Daily and Intermediate Cover

1. High void space limits the effectiveness of tire shreds in controlling disease vectors, orders, and infiltration; also tire shreds are flammable (Donovan, et al., 1996)

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2. May be OK if 50/50 mix of tire shreds and soil is used

    a. Has been used in this application in the Roberts County Lanfill, South Dakota; reported that 50/50 mix of tire shreds and clay stored in stockpiles did not freeze making the mixture easy to work with and easy to spread in thin or thick lifts (Donovan, et al., 1996)

    b. Used in Franklin County Sanitary Landfill, Virginia; Virginia Dept. of Environmental Quality required that the mixture contain at least 50% soil and that the tire shreds be no larger than 4 in. by 10 in. in size; approved for a six month trial in July, 1994; the trial was successful and it was given permanent approval in March, 1995 (Freeland, 1994; Vakili, 1995)

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XI. TIRE SHREDS FOR SEPTIC TANK LEACH FIELDS

A. Field Trial

1. Tire shreds have been used for leach field aggregate in a test project in Vermont; the septic system had a 1,000-gal. tank and served a four bedroom house (Chenette Engineering, 1992)

2. Leach field requires 25-30 c.y. of tire shreds - this translates into about 1,350 tires per leach field

3. Two-inch nominal size tire shreds were installed in two 4-ft wide by 70-ft long by 1-ft deep trenches

4. Placed 10-in. of shreds in the trench and compacted with one pass of the track of an excavator; distribution pipe placed in trench and covered with 4-5 in. of shreds

5. Construction time was about the same as with stone

6. Installed two lysimeters to measure water quality; tested filtered samples for 12 metals (arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, selenium, silver, zinc, nickel); on one of seven sample dates the drinking water standard for lead (primary standard) and iron (secondary standard) were exceeded; below standard on other dates; other metals were below standard

B. State of Virginia specifications

1. Tire shreds are approved as coarse aggregate in tile fields and may be substituted for gravel on a one-for-one volumetric basis (courtesy of Allan Lassiter, Virginia Dept. of Environmental Quality)

2. Trenches are to be covered with a geotextile (synthetic) fabric to prevent soil infiltration

3. Shreds are to be a nominal 2 inches in size and may range from one-half (1/2) to a maximum of four (4) inches in any one dimension

4. Wire shreds protruding more than one-half (1/2) inch from the shred are prohibited

5. At least 95% of the aggregate by weight shall comply with the above specifications

6. Fines are prohibited

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XII. ENVIRONMENTAL CONSIDERATIONS FOR USE OF TIRE SHREDS

A. Tire shreds above groundwater table

1. UMaine has monitored two above groundwater table projects for metals; in the Richmond project samples were taken from monitoring wells located in shoulder of road (Humphrey and Katz, 1995); in North Yarmouth Project, samples were collected using 10 ft by 10 ft basins located directly under tire shreds (Humphrey, et al., 1996); both projects had control wells that were located in conventional road sections
2. Metals with primary drinking water standards are below the limits; results for chromium are shown in Fig. XII-1
3. Metals with secondary standards are also below the limit except for manganese and iron; results for filtered samples of iron and manganese are shown in Figs. XII-2 and XII-3
4. Some laboratory studies indicated that zinc could be leached from tire shreds; however, for North Yarmouth, the zinc levels are consistently higher in the control section compared to the two tire shreds sections as shown in Fig. XII-4; in any event, the levels are below secondary drinking water standards
5. Tests for volatile and semi-volatile organics at North Yarmouth were conducted on two sampling dates - on both tests the results were "non-detect" for all measured compounds

B. Tire shreds below groundwater table

1. UMaine also conducted a three part study of the water quality effects of tire shreds below the ground water table; includes burying 1.5 tons of tire shreds below the water table in three different soil types (Downs, et al., 1996)
2. Metals with primary drinking water standards are below the limits
3. Limits for iron and manganese, which have secondary standards, were exceeded in up gradient (control), tire shred, and down gradient wells at all three sites; even though the background levels of these metals exceed, tire shreds clearly increase the concentration of these metals; so tire shreds can only be used below groundwater table in locations where higher levels of iron and manganese can be tolerated
4. Tire shreds increased the level of zinc, but concentrations were still more than two orders of magnitude below its secondary drinking water standard

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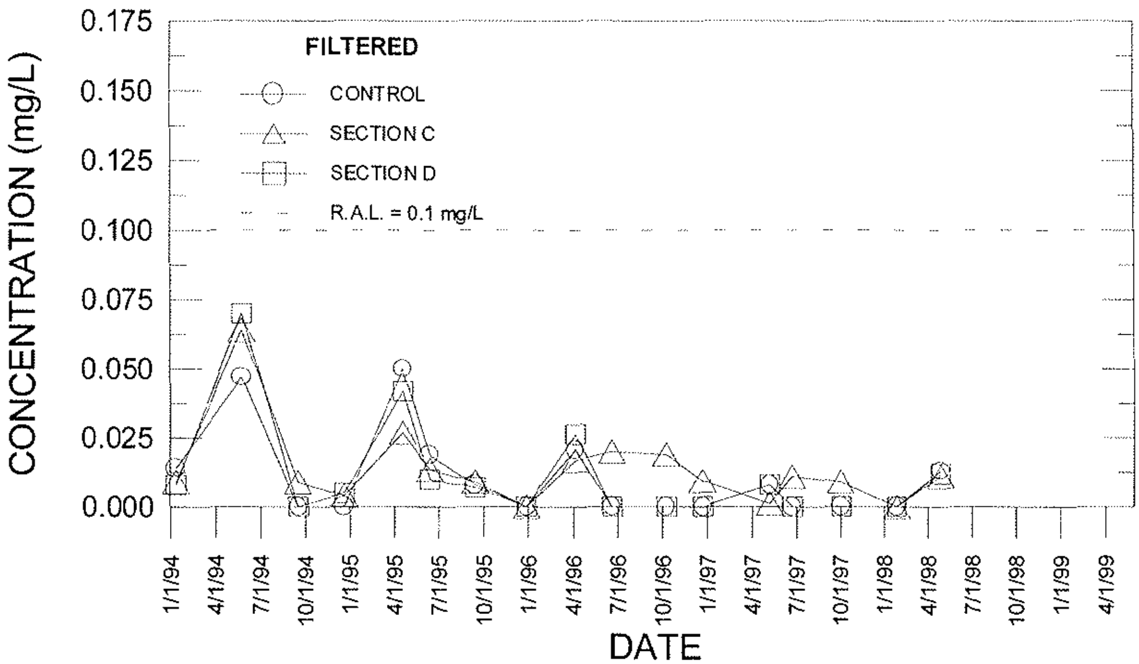

Fig. XII-1. Chromium levels for filtered samples at North Yarmouth field trial.

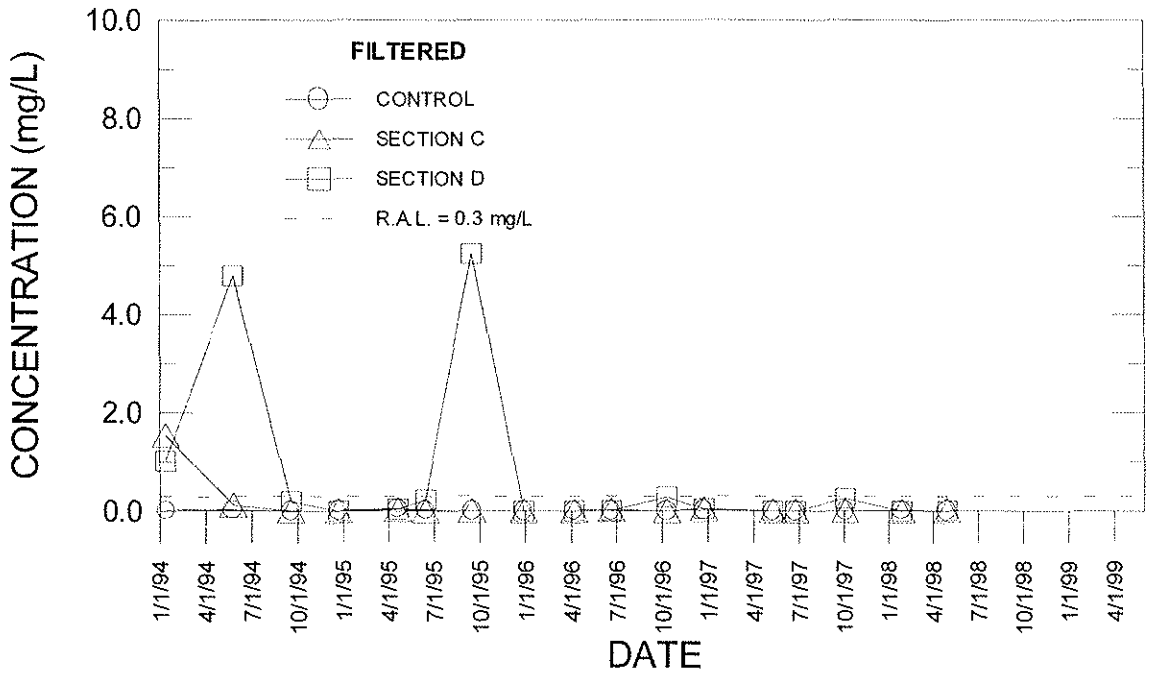

Fig. XII-2. Iron levels for filtered samples at North Yarmouth field trial.

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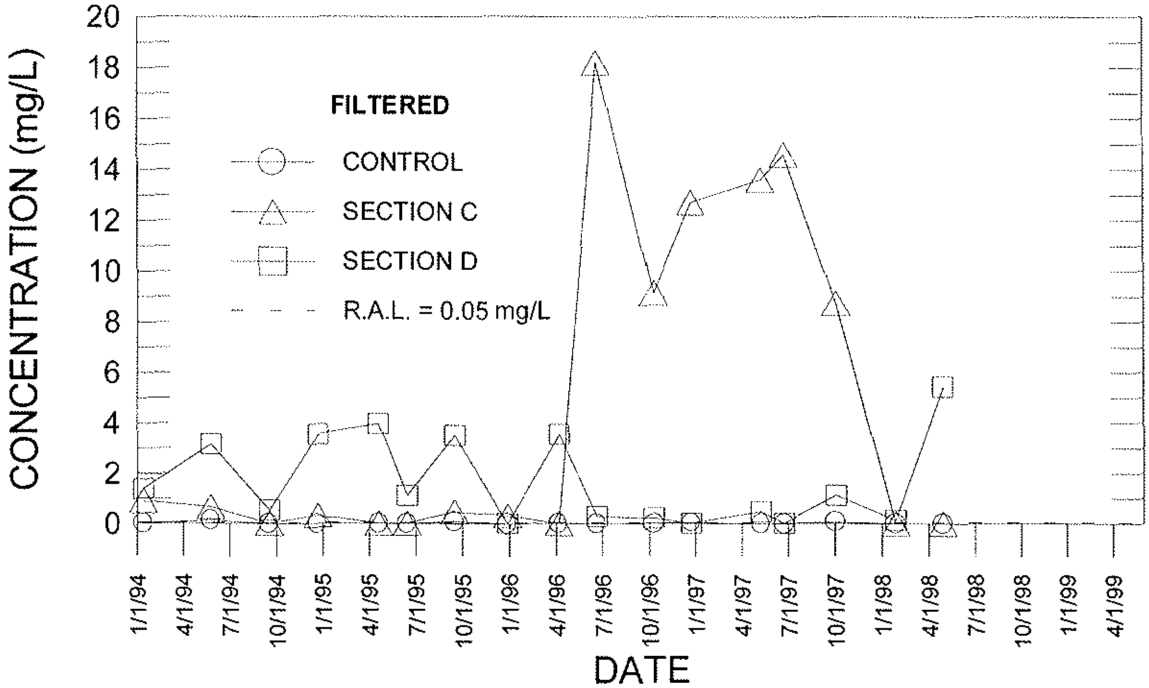

Fig. XII-3. Manganese levels for filtered samples at North Yarmouth field trial

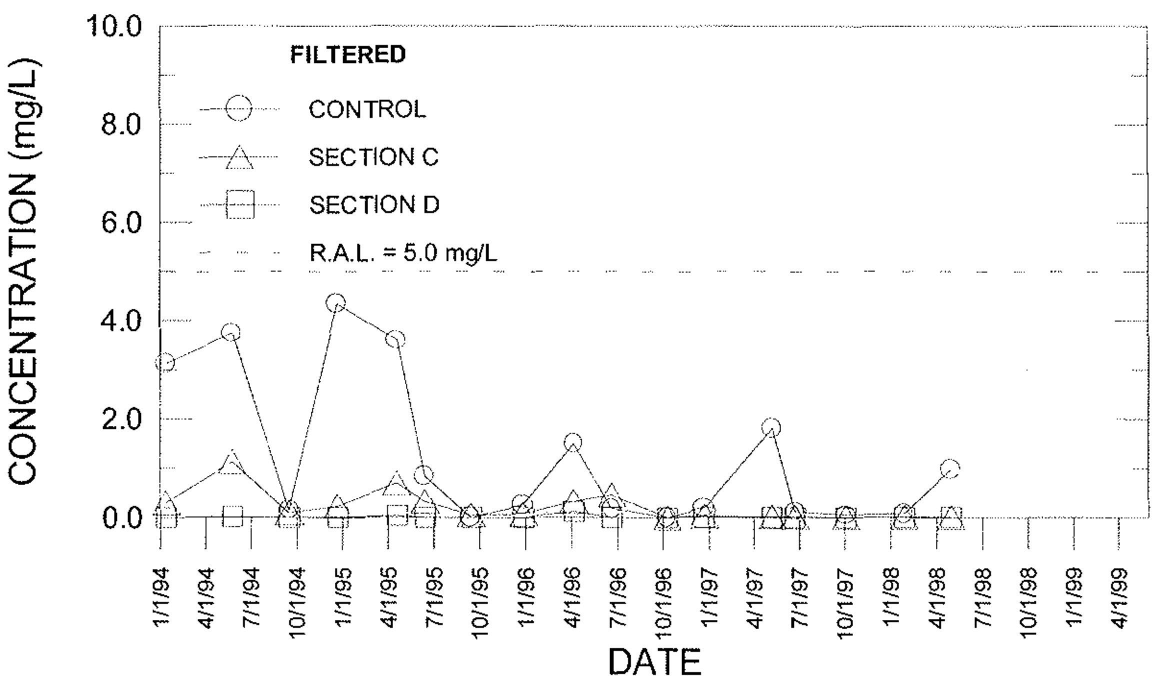

Fig. XII-4. Zinc levels for filtered samples at North Yarmouth field trial

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5. Organics

a) For samples taken directly from the tire shred filled trench, low levels of some volatile and semi-volatile organic compound were detected; the highest concentrations were of cis-1,2-dichloroethene; results for this compound are shown in Fig. XII-5; on all but one sampling date, the level were below the drinking water standard of 70 μg/L.

b) Except for a few isolated sampling events, the concentration of all compounds that have a drinking water standard were below the standard. Moreover, levels of organics are generally below detection limits after the water had moved only 2 ft through soil. Thus, it appears that tire shreds can be placed below the groundwater table with negligible release of organic compounds.

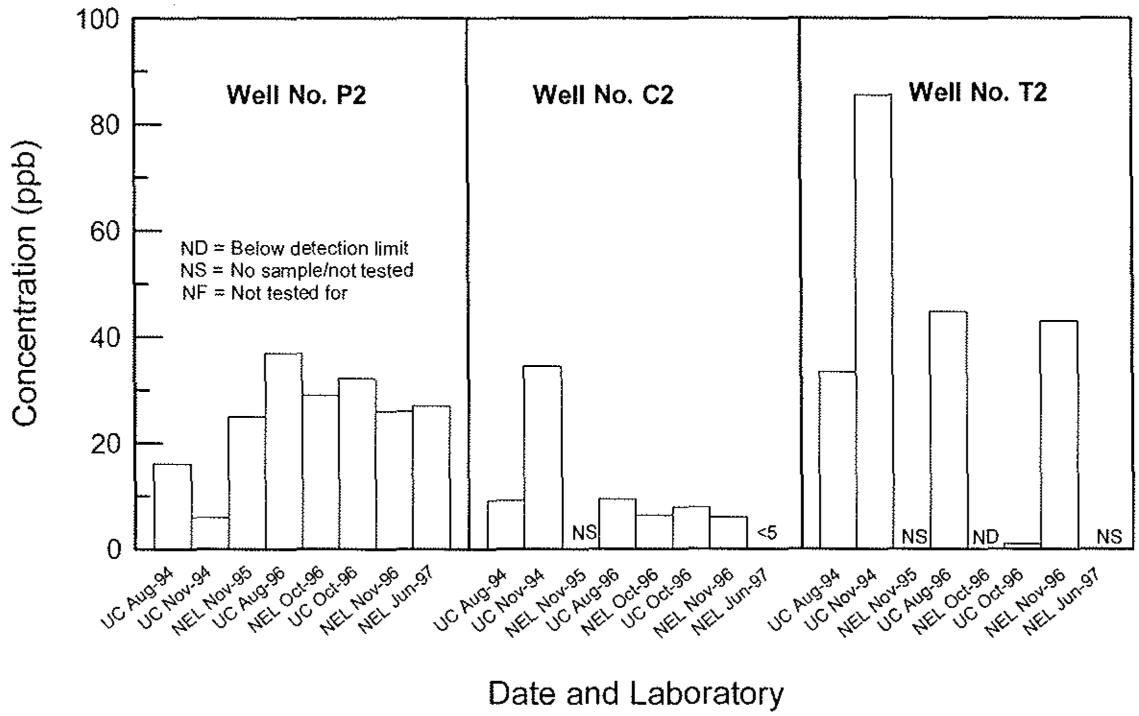

Fig. XII-5. Cis-1,2-dichloroethene results for samples taken from tire shred filled trench.

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XIII. EXOTHERMIC REACTIONS IN TIRE SHRED FILLS

A. Tire shred fills which have experienced an exothermic reaction

1. Ilwaco, Washington (Humphrey, 1986)

   a) Tire shred fill used as lightweight fill to repair 140-ft gap in road caused by landslide; project is adjacent to the mouth of the Columbia River

   b) Cross section through slide repair is shown in Figure XIII-1

      (1) Bottom of slide covered by 4-ft thick rockfill blanket
      (2) Tire shred layer was 26 ft thick; 1.75H:1V side slope; top of tire shred fill covered by geotextile
      (3) Beneath traveled way geotextile covered with 4 ft of granular fill followed by 0.65 ft of crushed surfacing top course; 0.35 ft (4.2 in) asphaltic concrete pavement
      (4) Sideslope covered with 2 ft of topsoil

   c) Tire shreds were typically 4 to 6 in. long by 2 in. wide; however, the upper part of the fill was constructed with 2 in. by 2 in. size shreds; tire shreds trucked to job site immediately after production

   d) Construction sequence

      (1) Construction began on Sept. 23, 1995; remove loose material from bottom of slide and place rockfill drain

      (2) Tire shred placement began on October 3, 1995

         (a) WSDOT resident engineer noted one truck load of shreds with a significant content of fine rubber
         (b) Placement completed on Oct. 18, 1995
         (c) Placed 4,000 tons of shreds
         (d) Rainfall was 4.8 in. during this period
         (3) Topsoil placement
         (a) Topsoil placed as the fill was brought up
         (b) Soil placed in upper part of slope came from cranberry bog

      (4) Road paved on October 31, 1995

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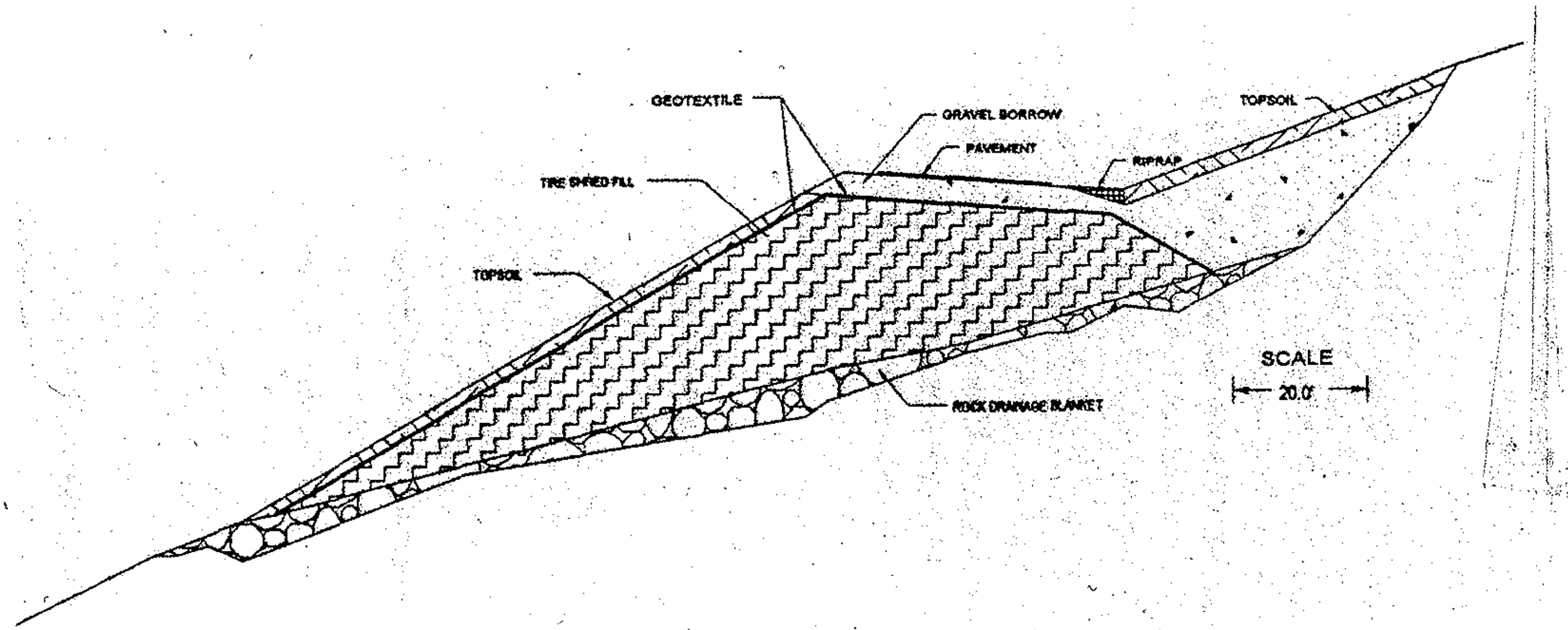

Figure XIII-1 Cross section through tire shred fill on SR 100 in Ilwaco, Washington (Humphrey, 1996).

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e) Evidence of problems

(1) First evidence of problems was as few days before Dec. 25, 1995 - crack in pavement

(2) On Jan. 3, 1996, water vapor and heat were observed

f) Monitoring program

(1) Temperature - zone of high temperature confined to shoulder of road; temperatures as high as 160 deg. F were measured

(2) Settlement

(3) Water quality - pH of water emerging from toe: 6.3 on Jan. 17 and 5.2 on Jan. 30

(4) Also monitored air and nearby soil for contamination

g) By late February it was evident that the rate of reaction was increasing; the fill was removed.

2. Garfield County, Washington

a) Tire shred fill used to fill ravine to straighten gravel surfaced county road

b) Total height of embankment was 49.5 ft with 45 ft being tire shreds; side slopes were 1.5H:1V; 6-ft diameter corrugated metal pipe used to carry intermittent creek beneath embankment; 4 to 7 ft of gravel placed on road surface; 18-in or less of topsoil placed on sideslopes; a cross section is shown in Figure XIII-2

c) Construction began in late Fall, 1994 and was completed in Spring, 1995

d) Tire shreds were placed in 12 to 18-in. lifts and compacted by D-7 bulldozer

e) Shreds placed in lower part of fill were produced by hammer mill and had a significant amount of exposed steel; while shreds placed in upper part of fill were produced by shearing

f) For the period Spring, 1995 through October 7, 1995 some minor settlement of crest road occurred; additional pit run gravel was placed to bring the road back to grade

g) Flash flood occurred on July 6, 1995

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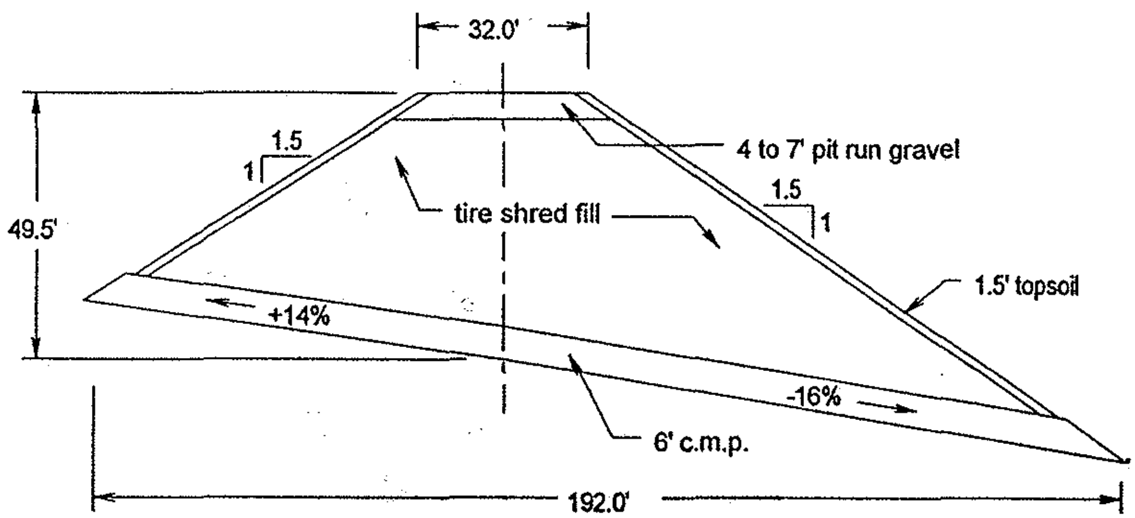

Figure XIII-2. Cross section through tire shred fill on Falling Springs Road in Grafield County, Washington (Humphrey, 1996).

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h) Passerby reported "smoke" coming from fissure in fill on Oct. 7, 1995; smoke was actually water vapor

i) Settlement occurred at faster rate from Oct. 7, 1995 through January 17, 1996; placed additional fill

j) Open flames observed on 4 sq.ft. area on January 17, 1996

k) Features observed during site visit are shown in Figure XIII-3; 4 to 6 ft of settlement of crest road; steam and water vapor emerging from much of downstream slope

3. Glenwood Canyon, Colorado

   a) Tire shreds used as backfill behind 70-ft high retaining wall adjacent to I-70 in Glenwood Canyon, Colorado

   b) Construction began in the fall of 1994 and was completed in the summer of 1995

   c) Front face made of 2-ft by 4-ft by 16-in. blocks formed from shredded tire rubber mixed with latex; backfill reinforced with geogrids; upper terraces covered with 2 ft of topsoil/compost mixture

   d) Cross section shown in Figure XIII-4

   e) First evidence of heating during the summer, 1995

   f) October 30, 1995, fire broke out on level 6

B. Tire shred fills which have not experienced an exothermic reaction

1. Over 70 projects where tire shreds used as fill for highway projects; most of these were constructed in Minnesota and construction information is limited

2. Projects with significant construction information are summarized in Table XIII-1

C. Reports of exothermic reactions in stockpiles at tire shred production facilities

1. Tire shred stockpiles

2. Crumb rubber stockpiles

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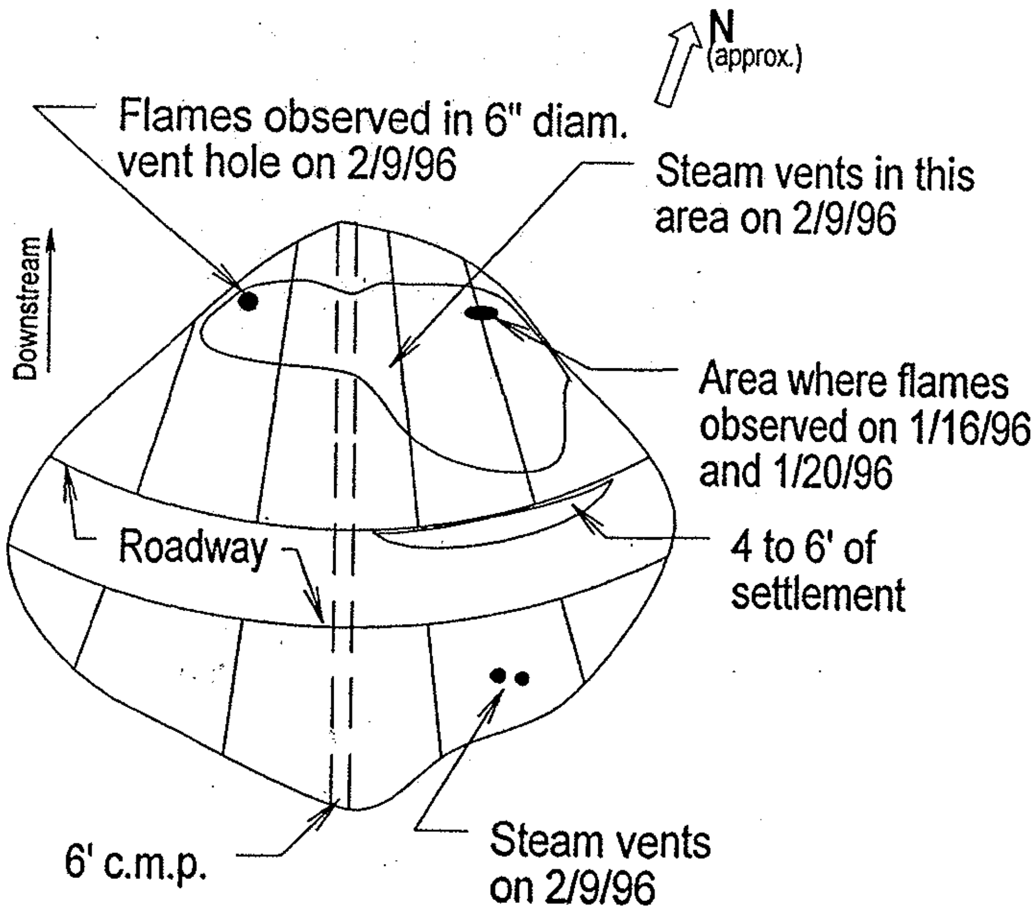

Figure XIII-3 Sketch showing locations of features observed during February 9, 1996, site visit (Humphrey, 1996).

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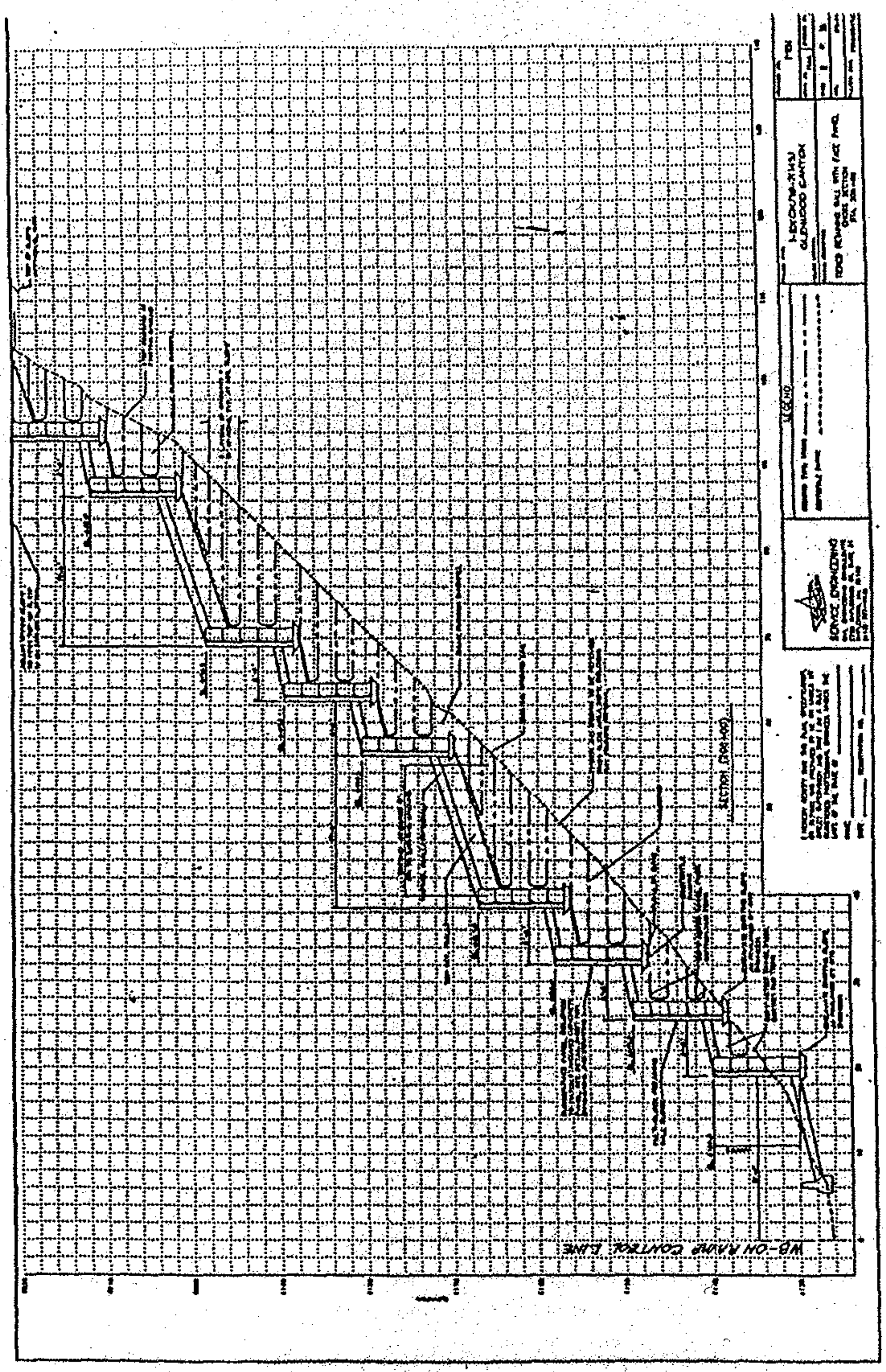

Figure XIII-4. Cross section through tire shred fill retaining wall Glenwood Canyon, Colorado (Humphrey, 1996).

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Table XIII-1. Summary of highway projects using tire shred fill (Humphrey, 1996).

State	Agency	Project Name	Year Built	Tire Shred Fill Thickness	Tire Shred Maximum Size	Shreds Mixed With Soil	Quantity of Tire Shred Fill Used	Cover thickness & type	
				(ft)	(in.)		(c.y./tons)	Top	Side slopes
CO	CDOT	I-76	1991	5	4	N	10,000/N.A.	3 ft granular & cohesive	N.A.
KY	KDOT	U.S. 27	1996	2 layers @2'	4	N	3000/N.A.	12 ft shot rock	40 ft shot rock
ME	Town	Richmond	1992	0.5 to 1.0	2	N	300/N.A.	1 to 2 ft granular	1 ft granular
ME	MDOT	N. Yarmouth	1993	2	3 & 12	N	1300/801	2.5 to 4.5 ft granular	2 ft granular
ME	MDOT	T31MD	1994	2	3 & 12	N	2325/1425	2 to 6 ft silty sand + 2.1 ft granular	2 ft silty sand
MN	USFS	Fourmile Lake	1989	2 to 3	-------	N	2488/N.A.	1 ft soil minimum	1 ft soil
MN	MDOT	Fosstom	1993	N.A.	12	N	2600/N.A.	N.A.	N.A.
MN	MDOT	Taylor's Falls	1994	15	12	N	N.A./900	5 ft granular	3 ft granular
MN	MDOT	Pine City	N.A.	15	12	N	30,000/N.A.	5 ft granular	3 ft granular
NC	NCDOT	13 projects	--------	20	3	Y	434 to 16,500	4 ft cohesive soil	4 ft cohesive soil
NC	NCDOT	A-10		5	3	N	Not Available	Geomembrane + 25 ft lightweight fill + 5 ft soil fill	5 ft fill
OR	ODOT	U.S. 42	1990	14	12	N	8260/5800	3 ft soil + 1.9 ft granular	3 ft soil
VA	VDOT	Rt. 646	1993	20	10	Y	55,000/N.A.	5 ft soil	4 ft soil
VT	VAOT	Middlesex	1990	18	3	N	2738/N.A.	Not applicable	2 ft earth borrow
VT	Town	Georgia	1990	0.75	2 to 4	N	1490/N.A.	1.75 ft gravel	Not applicable
VT	Town	Arlington Wall	1995	2	4	N	3000/N.A.	2 ft granular + 1 ft topsoil	Not applicable
WA	WDOT	Cosmopolis	1992	11	12 (est.)	N	11,000*/N.A.	2 ft granular	2 ft topsoil
WY	WDOT	South Pass	1994	15	>12	N	13,000/N.A.	5 ft granular	2 ft cohesive

*Loose measure

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D. Potential causes of exothermic reaction

1. Oxidation of exposed steel wires
2. Role of microbes in oxidation of steel wires
3. Oxidation of rubber
4. Microbes consuming liquid petroleum products
5. Potential aggravating factors in tire shred fills and stockpiles which have experienced exothermic reactions
   a) Small shreds and/or lots of exposed steel belt
   b) Presence of crumb rubber
   c) Topsoil placed directly on shreds
   d) Free access to oxygen

E. Design guidelines to minimize internal heating of tire shred fills (Ad Hoc Civil Engineering Committee, 1997)

1. General Guidelines for All Tire Shred Fills
   a) The tire shreds shall be free of all contaminants such as oil, grease, gasoline, diesel fuel, etc., that could create a fire hazard.
   b) In no case shall the tire shreds contain the remains of tires that have been subjected to a fire because the heat of a fire may liberate liquid petroleum products from the tire that could create a fire hazard when the shreds are placed in a fill.
2. Class I Fills (fills less than 1 m thick)
   a) Material guidelines. The tire shreds shall have a maximum of 50% (by weight) passing the 38-mm sieve and a maximum of 5% (by weight) passing the 4.75-mm sieve.
   b) Design guidelines. No design features are required to minimize heating of Class I Fills.

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3. Class II Fills (fills 1 to 3 m thick)

   a) Material guidelines.

      (1) The tire shreds shall have a maximum of 25% (by weight) passing the 38-mm sieve and a maximum of 1% (by weight) passing the 4.75-mm sieve.

      (2) The tire shreds shall be free from fragments of wood, wood chips, and other fibrous organic matter.

      (3) The tire shreds shall have less than 1% (by weight) of metal fragments which are not at least partially encased in rubber. Metal fragments that are partially encased in rubber shall protrude no more than 25 mm from the cut edge of the tire shred on 75% of the pieces and no more than 50 mm on 100% of the pieces.

   b) Design guidelines.

      (1) The tire shred fill shall be constructed in such a way that infiltration of water and air is minimized. Moreover, there shall be no direct contact between tire shreds and soil containing organic matter, such as topsoil. One possible way to accomplish this is to cover the top and sides of the fill will a 0.5-m thick layer of compacted mineral soil with a minimum of 30% fines. The mineral soil should be free from organic matter and should be separated from the tire shreds with a geotextile. The top of the mineral soil layer should be sloped so that water will drain away from the tire shred fill. Additional fill may be placed on top of the mineral soil layer as needed to meet the overall design of the project. If the project will be paved, it is recommended that the pavement extend to the shoulder of the embankment or that other measures be taken to minimize infiltration at the edge of the pavement.

      (2) Use of drainage features located at the bottom of the fill that could provide free access to air should be avoided. This includes, but is not limited to, open graded drainage layers daylighting on the side of the fill and drainage holes in walls. Under some conditions, it may be possible to use a well graded granular soil as a drainage layer. The thickness of the drainage layer at the point where it daylights on the side of the fill should be minimized. For tire shred fills placed against walls, it is recommended that the drainage holes in the wall be covered with well graded granular soil. The granular soil should be separated from the tire shreds with geotextile.

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F. Temperature performance of recent tire shred projects

1. North Abutment Fill, Topsham, Maine

   a) This project was under construction during the period when the guidelines were being developed. It incorporates some of the features recommended by the guidelines to limit embankment heating. Specifically, the lower 2/3 of the tire shred fill was constructed with larger shreds meeting the guidelines (Maine DOT calls this Type B shred). However, the upper 1/3 was constructed with smaller shreds containing an excess amount of material passing the No. 4 sieve (Maine DOT calls this Type A shred). This was done as an expedient since these had already been stockpiled near the job prior to the problems in Washington State. As recommended by the guidelines, the top and sides of the fill were covered with 2 ft of fine grained soil to limit inflow of water and air into the tire shred zone. A cross section of this project is shown in Fig. VI-5.

   b) Temperature sensors were installed at three levels in the tire shreds as well as the soil under and over the tire shred zone. The lower two levels of sensors in the shreds were in the larger Type B product while the upper level was in the smaller Type A product.

   c) The temperatures in the smaller Type A shreds are shown in Fig. XIII-5. The peak temperatures was 40°C (104°F). In contrast the peak temperature in the larger Type B shreds was 29°C (84°F). This suggests that the smaller Type A shreds are more susceptible to heating than the larger Type B shreds.

   d) The long term trend shows that the temperatures are generally decreasing although some sensors experience a small seasonal increase in temperature during the summer.

2. Jetport Tire Shred Fill, Portland, Maine

   a) This project was built in full compliance with the guidelines to limit embankment heating. The project used larger Type B shreds, the maximum thickness of a tire shred layer was 10 ft, and fine grained soil was used to cover the side slopes and top of the tire shred zone. A cross section is shown in Fig. V-7.

   b) Temperatures in the lower and upper tire shred layer are shown in Figs. XIII-7 and XIII-8. The warmest temperatures occurred at the time of placement when the blank tire shreds were exposed to the summer sun. Once covered by soil the temperatures began to slowly decrease. These results support the effectiveness of the guidelines to limit embankment heating.

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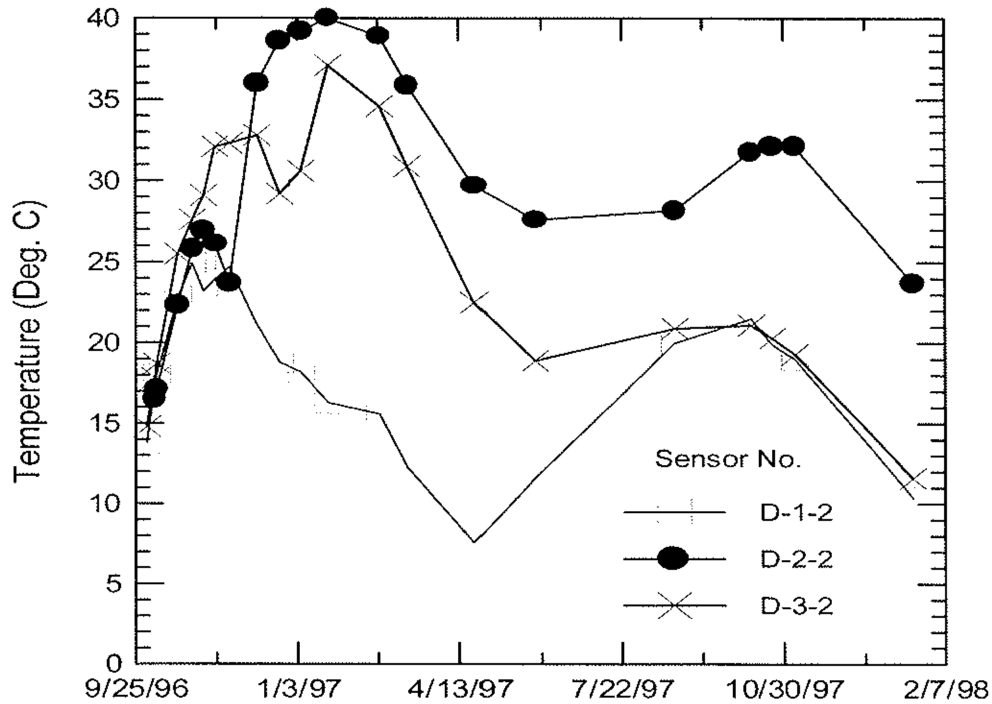

Fig. XIII-5. Temperatures in larger Type B tire shreds at the North Abutment Fill in Topsham, Maine.

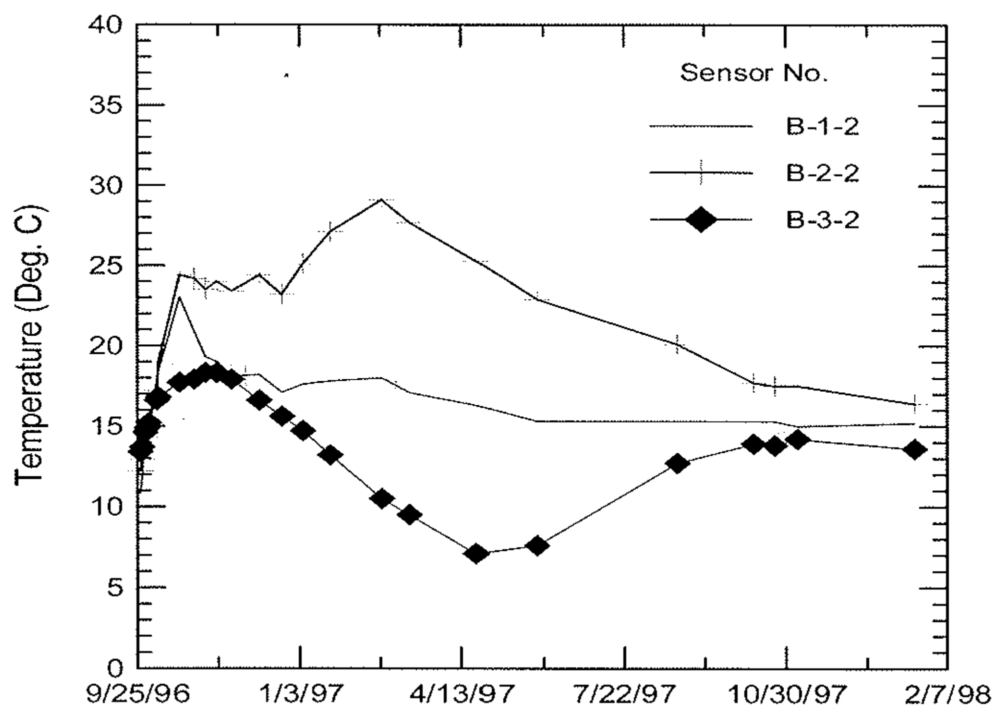

Fig. XIII-6. Temperatures in smaller Type B tire shreds at the North Abutment fill in Topsham, Maine.

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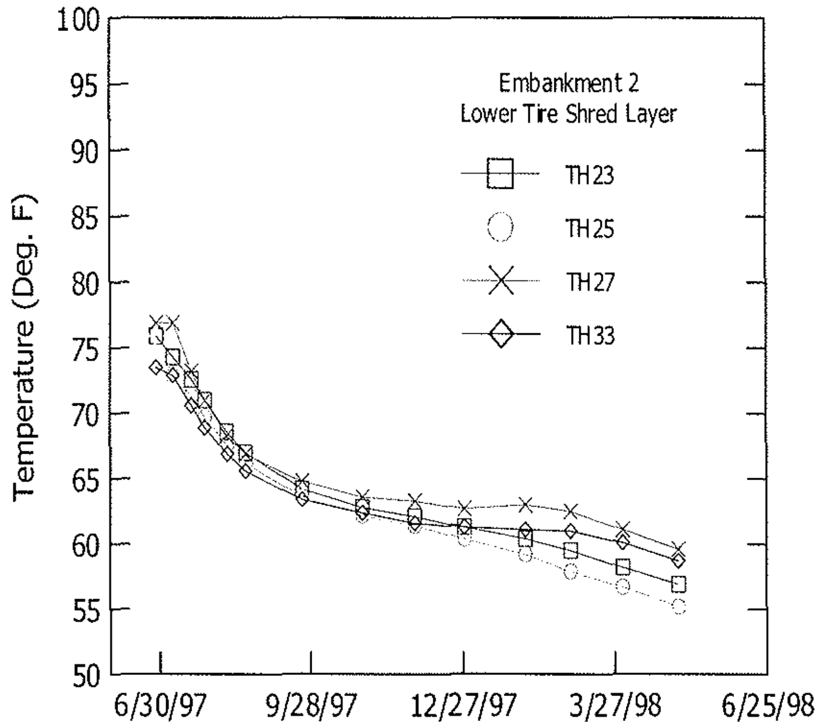

Fig. XIII-7. Temperatures in lower tire shed layer at Portland Jetport.

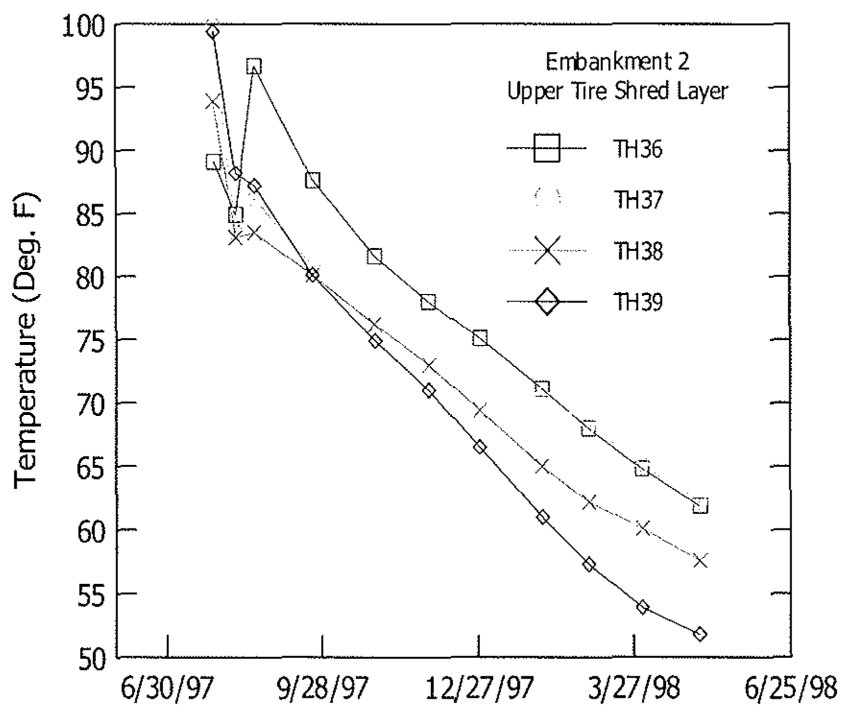

Fig. XIII-8. Temperatures in upper tire shred layer at Portland Jetport.

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XIV. CONSTRUCTION SPECIFICATIONS FOR TIRE SHREDS

A. Example specification - example specification is attached to these notes

B. Pay quantity - cubic yard vs. ton

1. Cubic yard measure

    a) What is the definition of a cubic yard - loose in the truck, compacted in-place, or compacted and compressed under weight of overlying soil cover? -- be very clear in your contact documents and make sure all parties understand

    b) Cubic yard, loose in the truck - general contractor assumes liability for exact quantity of tire shreds used

    c) Cubic yard, in-place - tire shred supplier assumes liability for exact quantity of tire shreds used

    d) Because of uncertainty, an experienced contractor will give higher bid price

2. Ton measure

    a) The owner assumes liability for exact quantity of tire shreds used

    b) May get lower unit price from contractor because of reduced uncertainty

    c) Requires additional effort on part of owner to keep track of weight tickets

XV. CONSTRUCTION TIPS

A. Three things you need for a successful job

1. Good communication

2. Good communication

3. Good communication

B. Stockpiling tire shreds

1. The problems I've had with all my tire shred jobs is getting tire shreds delivered to the job site at a rate faster than they are used by the contractor; problem is two fold - producer can only make tire shreds at fixed rate (for example 8 c.y. per hour) and need lots of trucking capacity if job site is located great distance from producer

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2. One solution is to stockpile tire shreds near the job site before construction

3. Related problem is that tire shred producer and contractor tend to underestimate volume of tire shreds needed to complete job

C. Spreading tire shreds

1. Tire shreds should be spread with track mounted dozer or track mounted loader

    a) Tracks eliminate problems with flats

    b) My experience is that it is easier to spread 3-in. tire shreds with a small bulldozer than a big bulldozer

2. Maine specification for final grade is 3 in. above or below specified grade - can easily be obtained

D. Compacting tire shreds

1. For 3-in. tire shreds, I recommend 12-in. compacted lift thickness; compact with heavy vibratory smooth drum or vibratory sheeps foot roller; heavy, standard-width track dozer also OK; 6 to 8 passes is about right

2. For larger shreds others have had satisfactory results with 3-ft lifts compacted by D-8 size dozer

E. Compacting overlying soil layer

1. The spring of the tire shreds makes it more difficult to compact soil over tire shreds

2. For granular soils, I have found that they compact better if the soil is slightly weight of optimum

XVI. SUMMARY - WHY YOU SHOULD USE TIRE SHREDS ON YOUR NEXT JOB

A. Tire shreds have properties that road builders, engineers, and contractors need

1. Lightweight

2. Free draining

3. Good thermal insulator

4. Low lateral earth pressure

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5. Compressible
6. Vibration damping
7. Low-cost

B. Tire shreds have be used for the following applications (have already been done - not a pipe dream)

1. Lightweight embankment fill to increase slope stability or reduce settlement
2. Lightweight retaining wall backfill
3. Thermal insulation to limit frost penetration beneath roads
4. Highway edge drains
5. Vibration damping beneath rail lines

C. Can use lots of tires even on small jobs

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APPENDIX I – SAMPLE SPECIFICATION

19-X LIGHTWEIGHT TIRE SHRED FILL

19-X.01 Description.-- Lightweight tire shred fill shall consist of furnishing, placing, and compacting tire shred fill to the lines designated on the plans or specified or directed by the Engineer including the preparation of the areas upon which tire shred fill is to be placed.

19-X.02 Tire shreds.-- The tire shreds shall be made from scrap tires which shall be shredded into the sizes specified herein. They shall be produced by a shearing process. Tire shreds produced by a hammer mill will not be allowed. The tire shreds shall be free of any contaminates such as oil, grease, gasoline, diesel fuel, etc. that could leach into the ground water or create a fire hazard. In no case shall the tire shreds contain the remains of tires that have been subjected to a fire. The tire shreds shall be free from fragments of wood, wood chips, and other fibrous organic matter.

The tire shreds shall have less than 1% (by weight) of metal fragments that are not at least partially encased in rubber. Metal fragments that are partially encased in rubber shall protrude no more than 25 mm from the cut edge of the tire shred on 75% of the pieces and no more than 50 mm on 100% of the pieces.

At least one side wall shall be severed from the tread of each tire. A minimum of 90% (by weight) of the shreds shall have a maximum dimension, measured in any direction, of 300 mm and 100% of the shreds (by weight) shall have a maximum dimension of 450 mm. The tire shreds shall meet the following grading requirements:

Sieve Sizes	Percentage Passing
300-mm	100
200-mm	75-100
38.1-mm	0-25
4.75-mm	0-1

The gradation shall be measured in accordance with AASHTO T-27, "Standard Method for Sieve Analysis of Fine and Coarse Aggregate", except that the minimum sample size shall be 30 pounds (12 kilograms).

19-X.03 Placing. – The subgrade to receive tire shred material, immediately prior to spreading, shall conform to the compaction and elevation tolerance specified for the material involved and shall be free of loose or extraneous material. Tire shreds shall not be placed on soil containing organic matter.

The tire shred course shall be enclosed in a layer of filter fabric as shown on the plans. The filter fabric shall meet the requirements of Section 88-1.03 for underdrain filter fabric. The seams formed by adjacent strips of filter fabric shall be overlapped a minimum of 450 mm. Payment for filter fabric shall be considered incidental to construction of the tire shred fill.

Tire shred placement shall not be performed when material is frozen or a blanket of snow prevents proper compaction.

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19-X.04 Compacting. – The tire shred course shall be constructed in layers of uniform thickness and each layer shall be compacted in accordance with the requirements specified in this Section 19-X.04. The maximum compacted thickness of any tire shred layer shall not exceed 300 mm. Each layer of tire shreds shall be placed over the full width of the section. The tire shreds shall be spread with track mounted bulldozers, rubber tired motor graders, backhoes, or other equipment as needed to obtain a uniform layer thickness. The tire shreds as spread shall be well mixed with no pockets of either fine or coarse tire shreds. Segregation of large or fine particles will not be allowed.

Each lift of tire shreds shall be compacted with six passes of a vibratory smooth drum roller with a minimum static weight of 10 tonnes.

If the top of any layer becomes contaminated by addition of foreign material, including, but not limited to, soil, organic matter, oil, grease, gasoline, or diesel fuel, the contaminated material shall be removed and replaced with the specified material at no additional cost.

The completed side slopes and surface of the tire shred course shall be brought to a condition of uniform stability and compaction. To compensate for settlement of the tire shreds caused by the weight of the overlying soil, the top surface of the tire shred fill shall be overbuilt as shown on the plans. A tolerance of 75 mm above or 75 mm below the required grade and cross section will be allowed.

19-X.05 Low Permeability Cover. -- The sideslopes and top of the tire shred layer shall be covered by 0.5-m thick low permeability soil cover, unless otherwise shown on the plans or directed by the Engineer. The soil shall have an AASHTO classification of A-4, A-5, A-6, or A-7. The low permeability cover shall be placed and compacted as specified in Section 19-5. The top of the low permeability cover shall be sloped to drain with a minimum slope of 1%. Construction of the low permeability cover shall be paid in accordance with Section 19-7.05.

19.X.06 Waiting Period. -- After bring overlying aggregate base to the approximate final grade, the contractor shall allow a period of at least 30[1] days for settlement of the tire shred layer prior to final grading and paving.

19-X.07 Instrumentation. -- (Add this section if needed)

19-X.08 Measurement. The tire shred course placed in accordance with the widths and thicknesses shown on the plans and compacted as specified will be measured by the tonne.

19-X.09 Payment. Lightweight tire shred fill will be paid for by the tonne, which price shall include be full compensation for all labor, materials, equipment required to furnish an acceptable tire shred course and associated filter fabric layer.

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[1] Use 60 days if the tire shed fill cannot be uniformly tapered from the full thickness to zero over a horizontal distance of at least two times the thickness of the tire shred fill.

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APENDIX II - CALCULATION OF OVERBUILD

Tire shreds experience immediate compression under an applied load, such as the weight of an overlying soil cover. The top elevation of the tire shred layer(s) should be overbuilt to compensate for this compression. The overbuild is determined using the procedure given below with the aid of a design chart (Figure 1). Figure 1 is applicable to Type-B tire shreds (12-in. maximum size) that have been placed and compacted in 12-in. thick layers. To use this procedure with smaller Type A shreds (3-in. maximum size), increase the calculated overbuild by 30%.

SINGLE TIRE SHRED

The overbuild for a single tire shred layer is determined directly from Figure II-1. First, calculate the vertical stress that will be applied to the top of the tire shred layer as the sum of the unit weights times the thicknesses of the overlying layers. Second, enter Figure 1 with the calculated vertical stress and the final compressed thickness of the tire shred layer to find the overbuild. Consider the following example.

9-in. (0.75 ft) pavement at 160 pcf
2 ft aggregate base at 125 pcf
2 ft low permeability soil cover at 120 pcf
10- ft thick tire shred layer

The vertical stress applied to the top of the tire shred layer would be:
(0.75 ft x 160 pcf) + (2 ft x 125 pcf) + (2 ft x 120 pcf) = 610 psf

Enter Figure 1 with 610 psf and using the line for a tire shred layer thickness of 10 ft results in an overbuild of 0.68 ft. Round to the nearest 0.1 ft, thus, use an overbuild of 0.7 ft.

BOTTOM TIRE SHRED LAYER OF TWO LAYER CROSS SECTION

The overbuild for the bottom tire shred layer of a two layer cross section is also determined directly from Figure 1. The procedure is the same as described above for a single tire shred layer. Consider the following example.

9-in. (0.75 ft) pavement at 160 pcf
2 ft aggregate base at 125 pcf
2 ft low permeability soil cover at 120 pcf
10 ft upper tire shred layer at 50 pcf
3 ft soil separation layer at 120 pcf
10-ft thick lower tire shred layer

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The vertical stress applied to the top of the lower tire shred layer would be:
(0.75 ft x 160 pcf) + (2 ft x 125 pcf) + (2 ft x 120 pcf) + (10 ft x 50 pcf) + (3 ft x 120 pcf) = 1470 psf

Enter Figure 1 with 1470 psf and using the line for a tire shred layer thickness of 10 ft results in an overbuild of 1.13 ft. Round to the nearest 0.1 ft, thus, use an overbuild of 1.1 ft for the lower tire shred layer.

UPPER TIRE SHRED LAYER OF TWO LAYER CROSS SECTION

The overbuild of the top elevation for the upper tire shred layer a two layer cross section must include both the compression of the upper tire shred layer when the pavement, base, and soil cover is placed, and the compression of lower tire shred layer that will still occur under the weight of these layers. In other words, the lower tire shred layer has not yet compressed to its final thickness. This will only occur once the embankment reaches final grade. So the question is, "How much compression of the lower tire shred layer will occur due to placing the pavement, base and soil cover?" Consider the same two-layer example used above.

9-in. (0.75 ft) pavement at 160 pcf
2 ft aggregate base at 125 pcf
2 ft low permeability soil cover at 120 pcf
10 ft upper tire shred layer at 50 pcf
3ft soil separation layer @120 pcf
10-ft thick lower tire shred layer

Step 1. The final vertical stress applied to the top of the upper tire shred layer would be: (0.75 ft x 160 pcf) + (2 ft x 125 pcf) + (2 ft x 120 pcf) = 610 psf. Enter Figure 1 with 610 psf and using the line for a tire shred layer thickness of 10 ft results in a compression of 0.68 ft.

Step 2. Once the upper tire shred layer is in place, the vertical stress applied to the top of the lower tire shred layer would be: (10 ft x 50 pcf) + (3 x 120 pcf) = 860 psf. To determine the compression of the lower tire shred layer that has occurred up to this point, enter Figure 1 with 860 psf and using the line for a tire shred layer thickness of 10 ft results in a compression of 0.84 ft.

Step 3. Once the embankment reaches its final grade, the vertical stress applied to the top of the lower tire shred layer would be: (0.75 ft x 160 pcf) + (2 ft x 125 pcf) + (2 ft x

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120 pcf) + (10 ft x 50 pcf) + (3 ft x 120 pcf) = 1470 psf. Enter Figure 1 with 1470 psf and using the line for a tire shred layer thickness of 10 ft results in an overbuild of 1.13 ft. (Note: rounding to 1.1 ft would give the overbuild of the lower tire shred layer).

Step 4. Subtract the result from Step 2 from Step 3 to obtain the compression of the lower tire shred layer that will occur when the pavement, base, and soil cover is placed. 1.13 ft – 0.84 ft = 0.29 ft.

Step 5. Sum the results from Steps 1 and 4 to obtain the amount the top elevation of the upper tire shred layer should be overbuilt. 0.68 ft + 0.29 ft = 0.97 ft. Round to the nearest 0.1 ft. Thus, the elevation of the top of the upper tire shred layer should be overbuilt by 1.0 ft.

Final result: Overbuild the top elevation of the lower tire shred layer by 1.1 ft and the upper tire shred layer by 1.0 ft.

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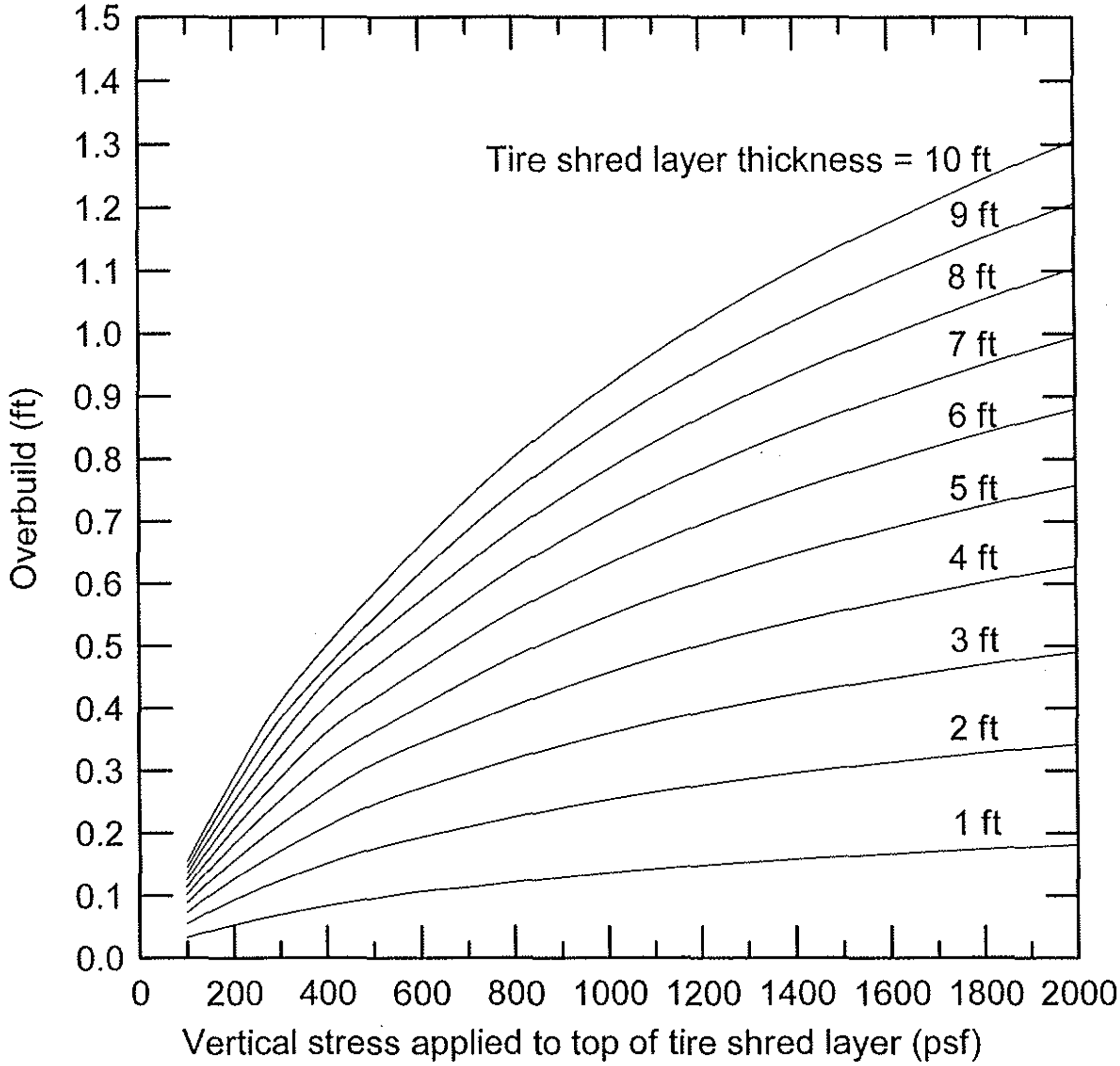

Figure II-1. Overbuild design chart for Type B shreds.

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NOTES:

Facts At a Glance

Tire Derived Aggregate (TDA)

1) ***Type A TDA*** – Typical, Three inch minus,

- 1 Ton = 1.4 cubic yards
- 1 Ton = 100 tires (PTE)
- In Place Density = 45-58 lb/ft^3
- Permeability › 1 cm/sec for many applications

Uses – Drainage material, septic leach fields,
Vibrations dampening layers under light rail tracks.
Gas collection media
Leachate collection material

2) ***Type B TDA*** – Typical, 12 inch minus

- 1 Ton = 1.5 cubic yards
- 1 Ton = 100 tires (PTE)
- In Place Density , 45-50 lb/ft^3
- Permeability › 1 cm/sec for many applications

Uses - Lightweight fill for embankments fills
Lightweight fill behind retaining walls