Evaluate the Uses for Scrap Tires in Transportation Facilities

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16. Abstract:

During the past two decades in the United States, scrap tires have been generated at an annual rate of one tire per person. Currently, the United States has 2 billion scrap tires in its stockpiles, and in Texas, this number is 150 million. Several applications have been developed for scrap tire use during the past decade. These include tire derived fuel (TDF) in industrial kilns and crumb rubber in asphalt. It is estimated that these account for less than 17 percent of scrap tire generation. Therefore, it is critical that alternative applications are developed where scrap tires can be used in large quantities. This research project was aimed at making an evaluation of existing practices and look into possible applications where TxDOT could use scrap tires in its construction projects. First, a literature review and a state-of-the-art survey was conducted for these studies. This was followed by the development of an economic analysis framework that could be used by TxDOT. A draft specification developed for the use of scrap tires in embankments is included in Chapter 8 of this report.

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Not intended for construction, bidding, or permit purposes. The engineer in charge of the research study was Sanjaya Senadheera, Ph.D, Texas Tech University.

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Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

IMPLEMENTATION STATEMENT

No implementation is recommended of the findings of this research study. Three applications for large-scale use of scrap tires were identified in Chapter 5 of the report. However, economic analysis revealed that they are not feasible alternatives at this moment to be implemented by TxDOT. However, recommendations are made for further research should TxDOT decide to pursue scrap tire research at a later date.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

NOTE: Volumes greater than 1000 l shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

(Revised September 1993)

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* SI is the symbol for the International System of Units. Appropriate

TABLE OF CONTENTS

Page

FIGURES

TABLES

ABSTRACT

It is believed that more than 2 billion used tires are currently stockpiled in the United States with an additional 285 million tires added each year. In Texas, it is reported that over 150 million scrap tires are stockpiled at various locations across the State and a further 18 million tires are added every year. Besides being an eyesore, these tire mounds pose fire hazards that result in air pollution and release of oils to nearby groundwater. Tire carcasses can also serve as breeding grounds for mosquitoes. Scrap tires cannot be placed in landfills because they trap gases and float to the top, punching holes in daily and landfill final covers. Care must be taken when stockpiling scrap tires for fear of exothermic reactions when undesirable compounds or circumstances are present. Therefore, it is prudent for Texas to find uses for its scrap tires without compromising the quality of potential end uses. Transportation facilities, which use materials in large quantities would be an ideal resource to explore such uses. The objective of this research is to investigate available information on the use of scrap tires in transportation facilities and to evaluate such uses. This research proposal team worked on collecting the information from earlier research projects in this field, to identify possible uses for waste tires to ease the burden on already scarce landfill space. In addition to a literature review, agencies such as the various State Departments of Transportation (DOT's), the Texas Commision for Environmental Quality (TCEQ), and the Scrap Tire Management Council (STMC) were contacted to collect information on scrap tire uses. Based on the information gathered from the literature review and state-of-the-art survey, three applications were identified as candidates for large scale uses of scrap tires in transportation. These applications were studied in detail for technical feasibility, cost and constructability to provide additional information to TxDOT to make decisions on their possible use.

CHAPTER 1
BACKGROUND AND SIGNIFICANCE OF THE STUDY

It is believed that more than 2 billion used tires are currently stockpiled in the United States with an additional 285 million tires added each year. In Texas, it is reported that over 150 million scrap tires are stockpiled at various locations across the State and a further 18 million tires are added every year. Besides being an eyesore, these tire mounds pose fire hazards that result in air pollution and release of oils to nearby groundwater. Tire carcasses can also serve as breeding grounds for mosquitoes. Scrap tires cannot be placed in landfills because they trap gases and float to the top, punching holes in daily and landfill final covers. Care must be taken when stockpiling scrap tires for fear of exothermic reactions when undesirable compounds or circumstances are present. Therefore, it is prudent for Texas to find uses for its scrap tires without compromising the quality of potential end uses. Transportation facilities, which use materials in large quantities, would be an ideal resource to explore such uses. The objective of this research is to investigate available information on the use of scrap tires in transportation facilities and to evaluate such uses. This research proposal team worked on collecting the information from earlier research projects in this field, to identify possible uses for waste tires to ease the burden on already scarce landfill space. In addition to a literature review, agencies such as the various State Departments of Transportation (DOT's), the Texas Commision for Environmental Quality (TCEQ), and the Scrap Tire Management Council (STMC) were contacted to collect information on scrap tire uses. Based on the information gathered from the literature review and state-of-the-art survey, three applications were identified as candidates for large scale uses of scrap tires in transportation. These applications were studied in detail for technical feasibility, cost and constructability to provide additional information to TxDOT to make decisions on their possible use.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

In the United States, during the past two decades, scrap tires have been generated at the rate of approximately one tire per person per year. The magnitude of the waste tire disposal problem was recognized by the federal government and stipulated in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) that, by 1997, one fifth of all highway projects must include 10 kg of recycled rubber per megagram of hot mix asphalt concrete and 150 kg of recycled rubber per megagram of sprayed binder. A study undertaken by the US Environmental Protection Agency (US EPA 1991) indicated that 77.6 percent of all scrap tires end up in landfills, stockpiles and other illegal dumps and the remainder went into uses such as export (5 percent), energy generation (10.7 percent) and other recycling measures (6.7 percent). Of the 6.7 percent that went into other recycling measures, 0.8 percent was used in the form of crumb rubber in pavements and only 0.1 percent was used as whole tires. These numbers indicated the pressing need for the identification of uses where large quantities of tires could be used that would prevent the accumulation of vast quantities of tires in landfills and illegal dumps. US EPA identified in 1991 that a scrap tire problem exists in the United States. There are several facets to this tire problem that may include the following.

- Tires are breeding grounds for mosquitoes, resulting in an increase in spread of diseases in addition to being a major nuisance. Some of the suggested preventive measures include tire shredding, fumigation of all shipped scrap tires, drilling holes in tires to facilitate drainage, and removal of tire bead to turn the carcass inside out. It has been reported that fires of shredded tire stockpiles are easier to extinguish than whole tires.

- Uncontrolled tire dumps are fire hazards and eyesores. Due to the air pockets within tires, it is extremely difficult to extinguish tire fires and some have burned for months creating air polluting smoke and oily residues. Air pollutants from tire fires include toxic gases such as poly-aromatic hydrocarbons (PAHs), carbon monoxide, sulfur dioxide, nitrogen oxide and hydro-chloric acid. In addition, oils related to the gaseous compounds indicated above also leach into the groundwater resulting in pollution that may require millions of dollars to clean.

- Disposal cost of waste tires is becoming increasingly expensive and this may lead to an increase in illegal dumping.

There are several problems associated with the disposal of whole tires. Approximately 75 percent of the bulk volume of a tire is taken up by void space making the transportation of bulk tires costly. Over the years, it has been learned that disposal of tires above the ground creates mosquito and fire hazards. Whole tire disposal by burying requires a large land volume and trap gases in air pockets. Furthermore, some landfill operators have reported that tires tend to float or rise to the top of a landfill and at times even pierced the landfill covers. Due to these reasons, shredding of tires has become increasingly popular as a disposal alternative. Even though this reduces the mosquito problem and reduces the entrapment of air, it results in the exposure of steel wires in tires that has been attributed to several fires. It is believed that during hot weather, the steel wires heat up and cause the tire rubber to ignite. US EPA reported shredding costs of 17.9 and 24.4 cents per tire for tire shredding rates of 800 and 500 tires per hour respectively. Table 2.1 shows the results from the US EPA study.

Table 2.1 Landfill Cost of Scrap Tires in the United States by Region (US EPA 1991).

Mode of Disposal	**Cost Item**	**Cost by Region**			
		Northeast	**Midwest**	**South**	**West**
Shredded Tires	Landfill Fee ($/ton)	45	18	16	13
	Process Cost ($)	25	25	25	25
	Total	70	43	41	38
Whole Tires	Landfill Fee ($/tire)	1.08	0.75	0.50	0.35
	Landfill Fee ($/ton)*	121	84	56	39
	Process Cost ($)	0	0	0	0
	Total	121	84	56	39
Saving by Shredding		51	41	15	1

***** - Assuming 1 tire weighs 20lb. on average.

2.2 TIRE COMPOSITION AND CHARACTERISTICS

2.2.1 Tire Composition

Most people think of a tire as mostly made of rubber. Automobile and truck tires are, in general, a complex combination of metals, minerals and hydrocarbons. There are many constituent materials that go into the construction of a tire with the principal ingredient being either natural virgin rubber, synthetic rubber or recycled tire rubber. Automobile tires are mostly made of artificial rubber (Styrene and Butadiene polymers) and truck tires typically have natural rubber as the main constituent (Evans 1997). Rubber constitutes approximately 30 percent of a tire, by weight. Other materials include steel, nylon, polyester, rayon, carbon black, fiberglass, aramid and brass.

One of the most important components of a tire is its casing. It is the woven fabric that provides the shape to the tire, houses the inner tube and is the surface on which the rubber tread is vulcanized. The body or casing of a tire is constructed in layers called plies. These plies are typically laid one on top of the other at an angle (or bias) to each other. This angle is generally 45 degrees. They are always laid in pairs of plies. Most original passenger car plies were laid in two pairs, (or 4 plies) commonly known as bias-ply tires as shown in Figure 2.1.

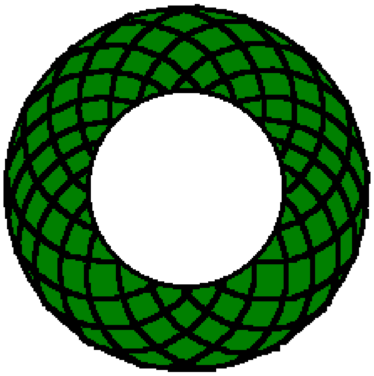


Figure 2.1 Bias-Ply Tire (Pirelli Company 1999)

The casing of a radial tire, illustrated in Figure 2.2, is also constructed in layers or plies, but, not to the angle as in bias-ply tires. The casing plies are laid out radially to the center of the tire and the angle is no more than 1 or 2 degrees in radial tires as compared to the 45-degree angle of bias-ply tires. Unlike most bias-ply passenger tires that are made up of 4 plies or more, most radial-ply passenger tires are of 2-ply construction in the casing.

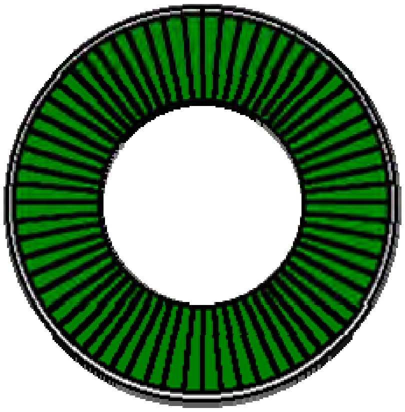


Figure 2.2 Radial-Ply Tire (Pirelli Company 1999)

Tires are made up of a number of components. Figure 2.3 and the following explanation gives a detailed description of the basic tire parts, their definitions and their location in the tire.

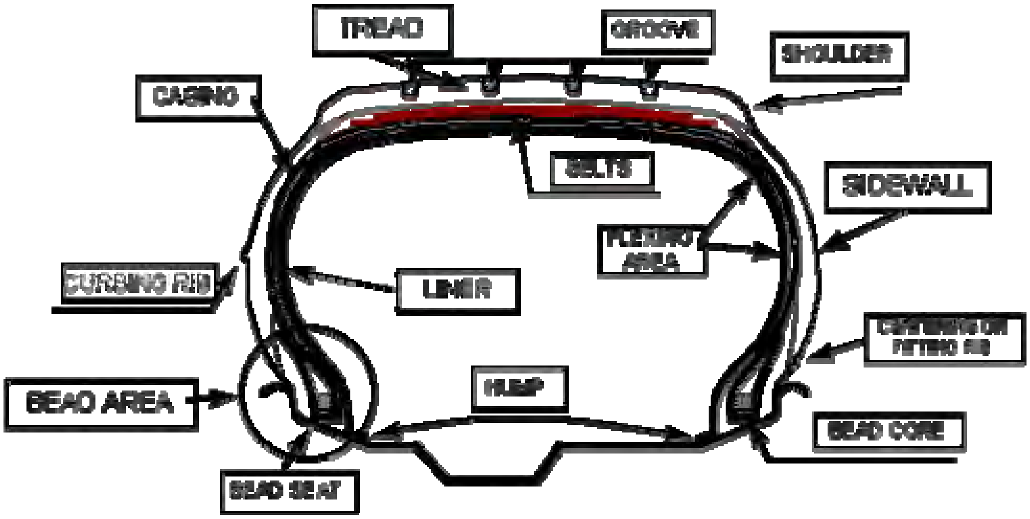


Figure 2.3 Basic Components of a Tire (Pirelli Company 1999)

- **Bead:** An inextensible hoop of high tensile steel wires, which anchors the plies and comforms to the rim seat to hold the tire onto the wheel rim.

- **Bead Seat:** Inner ledge portion of wheel rim where tire bead rests adjacent to the flange.

- **Belts:** Plies of tire chord beneath the tread that determines the diameter of the tire and stabilizes the tread by resisting deformation from braking and centrifugal forces.

- **Casing*:*** Tire body, composed of plies which form the tire's structure and give it shape. This is sometimes called the carcass.

- **Grooves*:*** **C**hannels between the tread ribs of a tire.

- **Liner:** Thin layer of halobutyl rubber inside a tire that contains the inflated air sometimes called the inner-liner.

- **Rib:** Part of tread pattern created by grooves that run circumferentially around the tire.

- **Rim:** The metal support for the tire. The beads of the tire are seated on the rim.

- **Sidewall:** The portion of the tire between the bead and the tread. It is flexible to soak up bumps, yet sufficiently stiff to limit tire rollover.

- **Tread:** Part of tire contacting the ground, made of tough rubber for traction & toughness.

Figure 2.4 is a cross-sectional view of radial passenger tire indicating the components and construction.

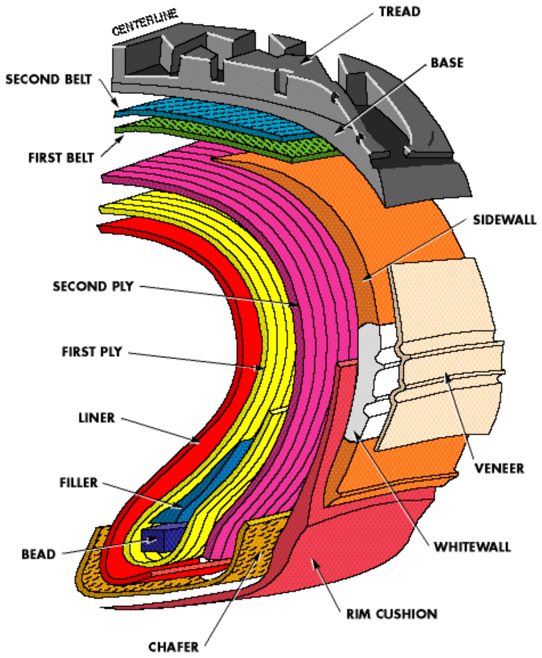


Figure 2.4 Radial Passenger Tire Construction (Cooper Tire & Rubber Company 1999)

Tire sizes are classified according to the rim diameter. Passenger car tires are approximately 14 - 16 inches in diameter and truck tires are 15 –18 inches in diameter. The sidewall of a tire provides information such as diameter of the wheel, width of tire, ply composition, and materials used. This is illustrated in Figure 2.5.

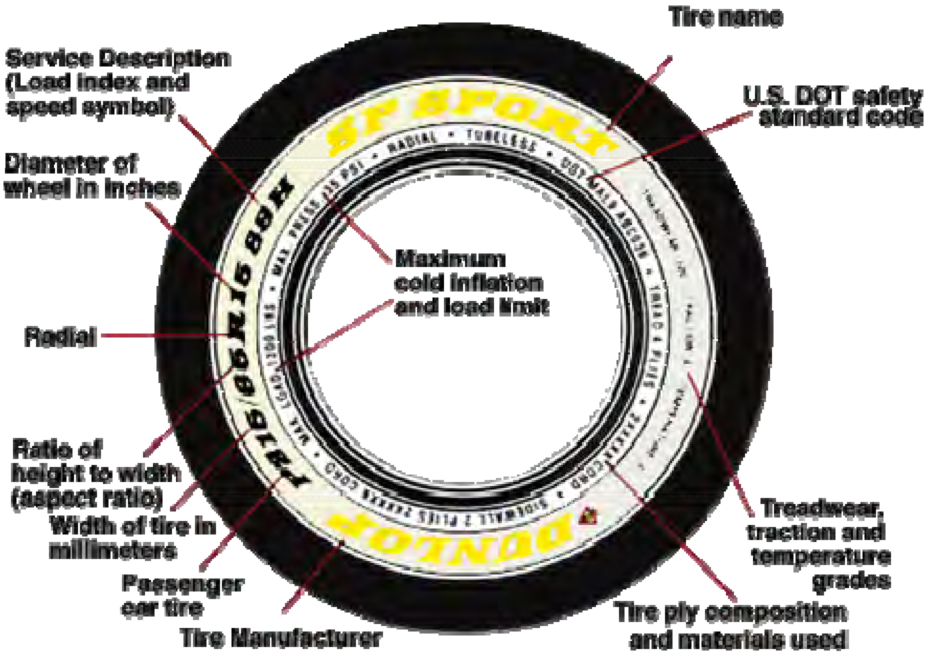


Figure 2.5 Sidewall of a Tire (Cooper Tire & Rubber Company 1999)

2.2.2 Decomposition of Stored Tires

A cooperative study conducted by the Firestone Tire & Rubber Company and Rutgers University on microbial degradation of tire rubber found that several microorganisms utilize the oils and rubber hydrocarbons of tire rubber (Crane et al. 1975). However, during this study, no microorganisms were found which selectively and completely cleaved the sulfur bonds in tire rubber. In addition, the growth of microorganisms that utilize extender oils and rubber hydrocarbons are suppressed by zinc oxide, anti-degradants and vulcanization accelerators. In all experiments, only a few percent of the scrap rubber were actually consumed by the microorganisms.

A study on microbiological degradation of rubber stated that both bacteria and fungi require a source of carbon for growth and may obtain this from organic material broken down enzymatically (Heap and Morrell 1968). Therefore, it was suggested that bacteria and fungi are potential destructive agents for rubber and some of the additives in rubber may be sources of food for microorganisms. It was also reported that Zinc oxide, which is one of the constituent materials in rubber, might act as a deterrent to growth of microorganisms. Protective agents such as paraffin wax used to prevent attack by ozone, “bloom” to the surface of the rubber and might also be a source of food for micro-organisms. In addition, Heap and Morrell (1968) also indicated the following comments regarding their study on microbial attack on rubber.

- Long chains of repeating Isoprene units in natural rubber are liable to oxidation. Vulcanized natural rubber may be attacked by ***Stemphylium macrosporoideum.***
- ***Spicaria violacea, Metarrhizium anisopliae, Fusarium*** species *and* ***Stemphyliopsis*** caused visible pitting and macro porosity in underground rubber-cased cables.

- ***Thiobacterium thio-oxidans*** attack sulfur in the vulcanized rubber by converting sulfur to sulfuric acid. A free sulfur content of <0.1% would likely avoid this problem.

- Butyl and nitrile rubbers are resistant to oxidation and there is little evidence of microbiological attack despite the presence of poly-isoprene units in butyl rubber.

- Silicone rubbers are generally considered to be resistant to microbiological attack.

Based on this information, the extent of problems that may result due to degradation of scrap tires is not clear. Heap and Morrell indicated that available evidence is confusing, contradictory and in some cases, misleading. They suggested that a distinction should be made between growth of fungi and actual attack and suggested further research in this area to reach concrete conclusions. This research team attempted to locate the latest information available on this subject but the search was unsuccessful. Therefore, long-term performance of structures using tire rubber, with regard to microbiological degradation, has not been clearly established.

2.3 HISTORY OF SCRAP TIRE USE

Use of waste tires in Texas is monitored by the TCEQ through a permit system. Table 2.2 lists a number of requests that were recently approved by TCEQ (1999). A number of other states have also promoted scrap tire use and some of these applications are listed in Table 2.3.

Table 2.2 Use of Bulk Tires and Tire Chips in Texas (TCEQ 1999)

Application	**Quantity (No. of Tires)**	**Remarks**
Whole tires as a ranch fence material	50,000	
Whole tires as planters for apple trees	6000	
Whole tires for side walls in a pistol range	1000	
Erosion control	1000	
Bank stabilization	700	
Reefs and fish attractors near Canyon Lake	2000	
A wave break at Lake Waco	100	
Tire chips are used in the drainfield area of the septic system.	About 100 tires for septic system	Tire chips are effective as a filtering medium

Edil and Bosscher (1992) conducted a comprehensive engineering characterization of shredded waste tires based on laboratory tests and field test projects. They recommended tire chips as a lightweight fill in highway applications if properly confined. They also indicated that tire chips have great potential as a drainage material in highway construction. Some of their observations are listed below.

- The specific gravity of tire chips range from 1.13 to 1.36 and the unit weight of a 100 tire-chip fill is 19 to 35 pcf.

- Densification of tire chips is best achieved by application of pressure rather than vibration. Unit weight of a mixture of tire chips and soil is significantly controlled by the percent soil in the mixture and to a lesser extent by soil type. Other factors such as water content and compactive effort are insignificant. Normal construction machinery is sufficient to place and compaction even though machinery with rubber tires may see problems of tires getting punctured by exposed wires in tire chips.

Table 2.3 Use of Tires and Tire Chips in Other States

	Agency/Location/Year	Application(s)	Quantity Used	Remarks
1	Wisconsin,1992 (Lockerby 1983)	Fill material		Shredded tires posed no major handling & placement problems. Some problems in controlling compressibility. Leachate showed little or no contamination.
2	New Jersey Div. of Fish, Game & Wildlife,1991 (Riggle 1992)	Artificial reef	120,000 tires/year	Used in Atlantic ocean to foster organism growth for fish habitats. Very successful application.
3	Ohio, 1991 (Biocycle 1991)	Temporary roads		Whole tires laid on soft soil for bank protection & run-off control. Road used by heavy trucks.
4	Carsonite Int'l, Nevada, 1970's (May 1995)	Sound barrier		When tires were used, cost reduced from \$15 to \$12 /ft^2. A very promising application.
5	North Carolina Div. of Marine Fisheries (NCDMF 1997)	Estuarine reef		
	• Black Walnut Point		220 tires	
	• Bayview Reef in Pamlico River		28,000 tires	
	• Quilley Point in Pungo River		19,200 tires	
	• Hatteras Island		16,280 tires	
	• New Bern		105000 tires	
	• Oriental		22,000 tires	
6	Encore Balers, Inc. (1999) New Mexico (1997) Mobile AL, 1996 Grand Isle, LA, 1991 Brainerd, MN 1990 Cohasset, MN, 1990	Firing range,fence, etc. Soil Elevation Soil Elevation Crash Barrier Erosion Control	5000+ bales 800+ bales Hundreds of bales	4 acres elevated. Used as lightweight fill for a park and a parking lot. Go-Cart & Grand Prix race tracks On power plant Supernate pond.
7	SRI International (Stanford Research Institute, CA)	Absorbers of Electromagnetic waves		Layered composite of tire tread, metal belt & other materials showed 90-95% wave absorption.
8	Goodyear Tire Co., (Chemical Engineering August 1978)	Artificial reef in Florida (Technique used in 2000 reefs)	3 million whole tires	Tires first punched to reduce buoyancy, Then compacted and bundled with ballast)

- Initial compression under load for tire chip-soil mixtures could be significant with 100 percent tire chips compressing as much as 40 percent of the initial thickness. Once this initial plastic compression is achieved, the material behaves like an elastic material.

- The elastic modulus of 100 percent tire chips is about 100 times smaller than a typical pure sand, but addition of a small amount of sand (30 percent) restores the modulus of the mix to values comparable to that of the sand. Clay-tire chip mixtures show lower moduli than sand-tire chip mixtures.

- It was observed that the overall performance of a gravel road built on tire chips is similar to most other gravel roads.

- To achieve minimum compressibility of the tire-chip fill, a soil cap should be used. Use of a geotextile to separate the soil cap and the tire-chip fill would prevent migration of soil from the cap to the tire-chip matrix. Tire chips used in road embankments perform better when used under thick soil caps (3 ft) when compared to a thin soil cap (1 ft).

- Tire chips improve frictional resistance of sands.

- Porosity of tire chips influences its stiffness. Porosity is affected by the size of tire chips and the presence of soil within tire chip voids.

- Tire chips have high hydraulic conductivity and water flow through tires is turbulent. Addition of at least 30 to 50 percent of sand (by volume) will reduce the hydraulic conductivity and compressibility significantly.

- Results from leaching tests indicated that tire chips have no adverse effects on ground water quality.

- The presence of groundwater does not preclude the use of tire chips, but they should not be used in highly acidic environments.

A number of state DOT’s and other agencies have constructed test projects using either whole or processed scrap tires in a number of applications. In order to evaluate the performance of these test projects, a telephone survey was conducted. Results from this survey and findings from additional technical literature are presented in the following sections under each primary civil engineering application category.

2.3.1 Geotechnical Applications

2.3.1.1 Earth retaining and erosion control structures: Tires as individual units or in the form of bales have been used in the construction of retaining walls or erosion control structures in the States of California, New Mexico, Minnesota and in countries such as Taiwan and Australia (Keller 1990; Encore Systems, Inc. 1999; Sulcal Constructions Pty Ltd. 1999). A bale is a unit consisting of compressed tires and it can be used as a building block. It is made using a machine called the baler which compresses approximately 100 passenger and light truck tires into a uniform block measuring 30" X 50" X 60". This is a volume reduction of about 4-to-1. The weight of a bale is approximately one ton. The baler is relatively inexpensive compared to the shredder systems and has low maintenance costs (Encore Systems, Inc. 1999)**.**

There are several advantages to using tire bales. Baling tires saves space through volume reduction. Tire baling has been proved to be less expensive than shredding. The process of baling tires is fast and does not require trained professionals. The completed bales are easily handled with simple tools and equipment such as a forklift, logger's clam or grappler. When same size tires are used to make one tire bale, because of the geometric uniformity of the bales, they can be easily stacked.

Tires in baled form do not hold water and therefore pose no threat to public health due to mosquitoes. Because of the higher density of a bale, its decreased surface area, and the lack of air pockets, the fire hazard is greatly reduced. Many successful projects have already been completed using the bales. In some uses, the bales are painted or coated with soil, shotcrete, plastic, foam or rubber compounds to improve the aesthetics.

The New Mexico Environment Department (NMED) constructed an erosion control wall using tire bales at Carlsbad, New Mexico. The project used about seven hundred thousand waste tires to stabilize approximately four thousand feet of a river bank (NMED 1999).

Scrap tires were also used for river and pond erosion control in Colorado and Minnesota respectively (Encore Systems 1999). Such applications are also widely in existence in the countries of Taiwan and Australia (Encore Systems, Inc. 1999; Sulcal Constructions Pty Ltd. 1999). All these applications used bales as building blocks in place of more conventional systems. The appearance of these walls is usually enhanced by the use of geo-textiles, rock facing or even vegetative facing.
The California Office of Transportation Research designed and tested several erosion control applications of scrap tires (Keller 1990). They found that tires used in combination with other stabilizing materials to reinforce an unstable highway shoulder and to protect a channel slope, proved to be a sound and economical alternative. Construction costs were reduced from 50 to 75 % of the lowest cost alternatives such as rock, gabion, (wire mesh/stone matting), or concrete.

2.3.2 Marine Applications

2.3.2.1 Reefs: Artificial reefs are constructed in the marine environment to duplicate conditions that cause concentrations of fishes and invertebrates on natural reefs. Several designs were proposed for reef units as part of a research study conducted by the EPA (Stone et al. 1974). They used scrap tires to construct reefs of different form, by tying them together and filling them with concrete. The aim of their research was to evaluate the different design forms by considering factors such as cost, ease of handling, and the effect on marine life. The total cost of these designs ranged between $0.26 and $5.63 per tire.

As of 1991, about 120,000 to 150,000 tires were used annually for marine reef construction in the US (US EPA 1991). The reefs are constructed by using tires split like bagels, leaving about six inches attached, and stacking them in the shape of a pyramid. Holes were drilled through this stack and about 45 pounds of concrete per tire was poured in the holes to anchor the reef. The 1800-pound, 3-foot high reefs were then hauled by barge 4 to 12 miles off the coast and dumped in 60 to 100 feet deep water. They then served as habitat for marine organisms and fish. These reefs cost approximately $3.50 per tire to build (US EPA 1991).

The New Jersey Division of Marine Fisheries constructed a tire reef in 1993 (Myatt et al. 1988). They came up with certain designs for reefs that used tires and concrete.

2.3.2.2 Shoreline Protection: Scrap tires were used for shoreline protection as early as 1970’s. A scrap tire revetment was constructed on the Eastern Shore of Maryland by stacking four tires and anchoring them to the ground (Crane et al. 1975). The cavity was filled with soil and vegetation was grown on it. The cost of construction was about $40 per liner foot compared to $100 per linear foot using the conventional materials and methods.

Breakwaters are off shore barriers that protect a harbor or shore from the strong impact of the waves. Scrap tires were used by the US Army Corps of Engineers to build breakwaters and were found to be effective on small-scale waves (USEPA 1991). Scrap tires for breakwaters and floats were filled with material, usually foam, which displaces 200 pounds of water.

During 1991, breakwaters and floatation devices consumed approximately 30,000 to 50,000 tires per year in the United States. Tire floats cost approximately $0.60 to $0.80 per pound compared to the economically closest alternative, foam-filled plastic, which cost $0.10 to $ 0.14 per pound of floatation (USEPA 1991).

More recently, rubber from used bias-ply truck tires are being used in marine applications such as fenders, dock bumpers, ferries, dolphins and barges by the Schyuler Rubber Company in the Washington State (Schuyler Rubber Company 1999). It is reported that laminated rubber offers good durability because of its good load deflection, energy absorption and toughness (when combined with nylon plies) properties.

On the whole, the use of scrap tires in marine applications appears to be a viable option, but the only point of concern is their long-term effect on ocean life and environment. Research that was conducted to study the effects of tire leachate on fresh water fishes revealed the presence of zinc and cadmium in amounts greater than normal (Evans 1997). Zinc toxicity was found to depend on the pH and the hardness of water. Certain fish showed higher zinc toxicity in higher pH waters. The species of fish that showed zinc poisoning in their tissues, under test conditions, included grass carp (Ctenopharyngodon idella), common carp (Cyprinus carpio), stickleback, (Gasterosteus aculeatus), guppy (Poecilia reticulata) and rainbow trout (Oncorhynchus mykiss). Newly hatched guppies exposed to zinc toxicity, showed growth inhibition, retardation of sexual maturity, damage to the gills, lever, kidney and skeletal muscle. Neurons of the mid and hind brain were affected in zinc-exposed larvae of herring (Clupea harengus).

It was concluded that acute to sublethal effects could be seen among certain species of aquatic life, in high salinity waters. Duration of tire exposure in the aquatic environment and the tire to water ratio, had also altered the response of certain organisms (Evans 1997). Lack of standardization and analytical methodology has made it difficult for comparison between various exposure studies done so far.

2.3.3 Transportation Applications

Waste tires have been used in a number of transportation engineering applications. Such uses include crumb rubber as an additive in asphalt cement, tire chips as aggregate replacement in pavement layers, lightweight embankment fills, non-structural sound-barrier fills and edge drains. Use of crumb rubber has been one of the first applications to use waste tires. Crumb rubber is fine particles of vulcanized rubber resulting from mechanical or cryogenic size reduction of scrap tires (US EPA 1991).

2.3.3.1 Asphalt rubber: Rubber modifiers added to asphalt in the form of crumb rubber were found to improve certain properties of asphalt binders. These improvements include reduced temperature susceptibility, enhanced elasticity of the asphalt-rubber binder, that leads to reduced rutting, increased resistance to thermal cracking and increased resistance to oxidation and hardening. Some of the disadvantages of this process include increased cost of the binder and the need for equipment modification at asphalt plants. Rubber is also added in the form of latex to improve the bond between asphalt and the aggregate and also to reduce the rutting potential of a HMA pavement by increasing its stiffness (NCHRP 1991).

The use of asphalt-rubber began in the late 1960s in Arizona. In 1989, 1.9 million tires were used in this application (US EPA 1991). The percentage of rubber in rubber asphalt is varied depending on the application. Generally, rubber content ranges from 15 to 25 % by weight of binder.

Rubber for asphalt-rubber is generally derived from recycled automotive tires. Typically, scrap tires are ground into small particles at ambient or cryogenic temperatures. Materials other than rubber that is included in tires, such as synthetic fibers and steel belts are removed. The resulting tire rubber particles, often referred to as crumb rubber, vary in size from No. 8 sieve to No. 200 sieve. Crumb rubber is blended with the neat asphalt cement at temperatures as high as 350°F to 400 °F. During this mixing process, rubber particles swell from three to five times their original volume and soften by the absorption of aromatic compounds from the asphalt cement. Heitzman (1992) reported that this increases the high temperature viscosity of the binder.

2.3.3.2 Rubber modified asphalt concrete: Rubber Modified Asphalt Concrete (RUMAC) is produced in a dry manufacturing process, where ground tire pieces are used as a part-replacement of aggregate in the asphalt concrete mix. The reinforcing materials present in the tires such as polyester, and steel must be removed before they are used. Typically up to 3% of the aggregates by weight of granulated rubber particles are added aggregate replacement. It has been reported that RUMAC is good for rehabilitation of pavements with severe cracking because they offer increased durability and increased flexibility at low temperatures and compared to conventional asphalt concrete mixes. In this application almost all of the rubber in waste tires is used including the tread and sidewall interliner (USEPA 1991).

2.3.3.3 Lightweight fill in road construction: Tire chips shredded to the size of four or six inches is used as a lightweight fill material in roads. They may serve as a cheaper alternative in areas where aggregate costs are higher. The free-draining capacity, durability, and good thermal insulation property are some of the characteristics considered to be favorable for the use of tire chips in embankments. Approximately 75 tires yield 1 cubic yard of tire chip fill in a compacted state and this may be classified as a high-volume application in civil engineering. Table 2.4 lists the State DOTs that experimented with the use of tire chips in embankment construction. The thickness of these embankments using tire chips varied from 0.75 feet to 20 feet and they had a topsoil cover of two feet or more (Humphrey 1996).

A study by Humphrey et al. (1992) investigated the shear strength and compressibility of tire chips for use as retaining wall backfill. They highlighted that tire chips in embankments can be considered as a large scale use of waste tires considering the fact that it uses approximately 75 tires per cubic yard of fill. The resulting rate of use is more than the rates stipulated by ISTEA, and furthermore, use of tire chips in embankments does not involve the complicated processes of producing crumb rubber and the mixing of crumb rubber with asphalt. Humphrey et al. listed the following key findings from their study.

- The specific gravity of tire-chips ranged from 1.14 to 1.27.

- Absorption of tire chips range from 2.0 to 3.8 percent.

- The compacted dry density of tire chips range from 0.62 to 0.64 Mg/m^3 (38.6 to 40.1 pcf).

- Tire chips show high compressibility during initial portion of the first loading cycle but the compressibility is significantly less during the subsequent unloading/reloading cycles.
- Amount of exposed steel belt seems to have an effect on some engineering properties of tire chips. Larger amounts of exposed steel belt appear to cause higher compressibility during the first loading cycle, higher Young's modulus during unloading/reloading cycles, lower coefficient of lateral earth pressure at rest (K_0), and lower shear strength. Lower K_0 value may make the tire chips a candidate as a retaining wall backfill material.

- The friction angle of tire chips range between 19° and 25° and the cohesion ranges between 8 and 11 kPa (160 and 240 psf).

The problem with this use is that several projects that used tire chips in embankments, noticed exothermic reactions occurring in the fill evolving smoke and heat. Among the projects listed in Table 2.4, two of the Washington DOT test project reported exothermic reactions in the embankment. Three case studies of these tire embankment failures are discussed later in Chapter 4 of this report.

Table 2.4 Highway Projects Constructed Using Tire Shred Fills (Humphrey 1996)

State	**Agency**	**Project Name**	**Year Built**	**Tire Shred Fill Thickness (ft)**	**Tire Shred Max. Size (in)**	**Shreds Mixed w/Soil**	**Quantity of Tire Shreds Used (cy/tons)**	**Cover Thickness and Type**	
								Top Layer	**Side Slopes**
CO	CDOT	I-76	1991	5	4	N	10,000.N.A.	3 ft. granular & cohesive	N.A.
KY	KDOT	US27	1996	2 layers @ 2ft.	4	N	3,000/N.A.	12 ft. shot rock	40ft. shot rock
ME	Town	Richmond	1992	0.5 to 1.0	2	N	300/N.A.	1-2ft. granular	1ft. granular
ME	MDOT	N. Yarmouth	1993	2	3 & 12	N	1300/801	2.5-4.5ft. granular	2ft. granular
ME	MDOT	T31MD	1994	2		N	2325/1425	2-6ft. silty sand +2.1ft. granular	2ft. silty sand
MN	USFS	Fourmile Lake	1989	2 to 3		N	2488/N.A.	1 ft. soil minimum	1ft. 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	5ft. granular	3ft. granular
MN	MDOT	Pine City	N.A.	15	12	N	30,000/N.A.	5ft. granular	3ft. granular
NC	NCDOT	13 Projects		20	3	Y	434-16,500	4ft. cohesive soil	4ft. cohesive soil
NC	NCDOT	A-10		5	3	N	Not Available	Geomembrane+25ft Lightwt. fill+5ft. soil	5ft. fill
WA	WDOT	Ilwaco	1995	Up to 26 ft.	6 in.	N	N.A./4000	4ft. crushed rock over geotextile	
WA	WDOT	Garfield Co.	1995	40-60 ft.	10-12 in.	N	N.A./12,000	4-7ft. pit run gravel base over tire fill	

CHAPTER 3
SCRAP TIRE SAFETY ISSUES

3.1 TIRE STOCKPILE FIRES

A significant number of large tire fires have occurred in the United States over the past several years. Scrap tire fires are distinct from the other conventional fires. Tire fires can burn over a long period of times and some fires have reportedly burned for several months. One reason for such longevity of tire fires is the continuous supply of oxygen from trapped air within a whole-tire pile. Relatively small tire fires may require a large community resource commitment and the cost is often beyond the reach of the capability of a typical fire department. The Scrap Tire Management Council (STMC) reported that environmental consequences of major tire fires are significant and a single passenger car tire can generate about two gallons of oil as it burns and liquifies. Some of the notable effects of major tire fires listed by STMC are given below.

- In Lincoln, Nebraska, the fire of a 150ft x 50ft x 10ft tire pile required one half of the equipment of the city fire department and it also utilized a good part of the department's overtime expenditure allocated for the year.

- A tire fire in Hagarsville, Ontario cost $1.5 million to extinguish and caused $3 million in damages.

- A ten acre fire in Catskill, New York required the services of 1000 fire fighters and another 1000 support personnel during the height of the fire.

- A tire fire in Rheinhart, Virginia issued a plume of smoke 3000 ft. high and 50 miles long with its fallout reported in three states. This fire also threatened the drinking water in the area with Lead and Arsenic contamination. The cleanup cost was estimated at $1.3 million.

The products resulting from the burning of scrap tires may depend on the extent of burning. Controlled burning of scrap tires, such as in furnaces, as done in many industrial kilns in this country, produce useful energy as well as water, inert residues and oxides of carbon, sulfur and nitrogen. However, uncontrolled burning may result in the release of thick smoke, a wide range of pyrolitic hydocarbons and ash residues that can pose environmental and human health risks. A scrap tire fire that is classified under uncontrolled fires may produce extensive amounts of the following compounds and the types and quantities may vary depending on factors such as tire type, burn rate, pile size, ambient temperature and humidity.

- Ash residues (carbon, zinc oxide, titanium oxide, silicon dioxide, etc.)

- Sulfur compounds (carbon disulfide, sulfur dioxide, hydrogen sulfide)

- Polynuclear aromatic hydrocarbons (benzo(a)pyrene, chrysene, benzo(a)anthracene, etc.)

- Oils (aromatic, naphthenic and paraffinic)

- Oxides of carbon and nitrogen

- Particulates and various aromatic hydrocarbons including toluene, xylene, benzene, etc.

Tire fire in a stockpile spreads in stages involving ignition and propagation, compression, equilibrium and pyrolysis (STMC 1997). The ignition is initiated when scarp tires decompose in the open air and form flammable vapors at temperatures in excess of 500 °C. The propagation is accelerated because the other tires, which have not caught up flame, also decompose rapidly at elevated temperatures as high as 210 ^{o}C. The speed of propagation is about two square feet per minute to a depth of about two cubic feet every five minutes. Next is the tire compression stage when the top layers of burnt tires collapse into strips. During this stage, the heat and smoke effects increase dramatically. As the fire grows, it generates higher temperatures and voluminous amounts of smoke and the unburned products of combustion contribute maximum to the smoke. Equilibrium is reached when the fire looks like a low open flame, deep-seated internal fire with an ash coating on top. Since the pile in this state has totally collapsed, due to the downward pressure, oil is pushed out of the fire and possibly into the ground and the surroundings.

3.2 SUGAWA'S AUTOCOMBUSTION THEORY

Sugawa (1993) conducted a through investigation of the possible causes of tire stockpile fires at the Fire Sciences Institute of the Tokyo College of Science. He conducted thermal analysis and gas chromatography to explain spontaneous combustion of a tire shred fill and to characterize the mechanism of tire fire propagation. His experiments were based on the Frank-Kamenetskii self-ignition theory (Bowes 1984). Sugawa's application of this theory to tire fires was based on the following observations.

1. Anti-oxidants are added to tires preventing them from oxidizing during their useful lives, but when these additives cease to function, oxidation gradually progresses.

2. Oxidation is an exothermic (heat generating) process and this generated heat, when retained within adiabatic (no heat loss) layers of tire chips, would heat the tire chips further, thus promoting decomposition and further oxidation.

3. This chain reaction of self-generation of heat leading to adiabatic heat retention and further heat generation by oxidation could raise the temperature of the tire chips to the point of ignition.

Sugawa also made the following observations from his experimental work.

1. The heat generation in tire chips is due to thermal decomposition of the base material SBR (Styrene-Butadiene Rubber) and the volatilization of additives.

2. Tire chips first begin to generate heat (about 200 Joules per gram) and lose weight (about 5%) between 200 and 300 °F. When accumulated tire chips are stored for a long period of time, this heat build-up could cause spontaneous combustion.

3. Between 200 and 300 °C, heat generation in used tire chips is due to oxidation.

4. As rubber ages, more heat is generated by it.

Sugawa calculated the thermal characteristics of tire chips (activation energy, calorific value and thermal conductivity) and used these values to simulate tire stockpile fires using the Frank-Kamenetskii thermal ignition theory. The spontaneous ignition of a material depends on the balance between the amount of heat produced and the amount of heat dissipated. Frank-Kamenetskii thermal ignition theory developed a physical model for a system capable of spontaneous combustion. Using this theory, Sugawa showed that, in the case of a tire shred fill, depending on the ambient temperature, there exists a critical size of the adiabatic tire shred mass that will decide whether the mass will generate spontaneously combustion. Based on this approach, a series of charts were developed relating the tire stockpile size and ambient temperature to identify ignition and no-ignition zones as shown in Figure 3.1.

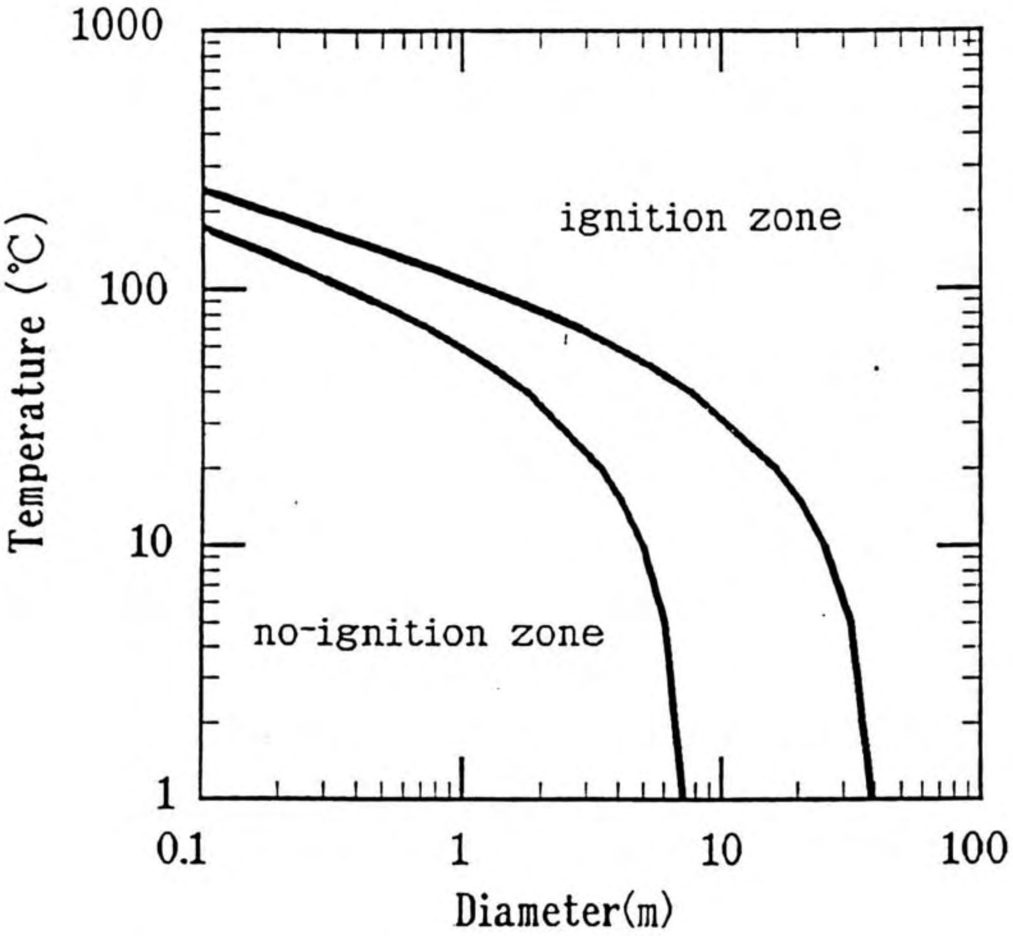


Figure 3.1 Chart of Critical Conditions of Atmospheric Temperature and Sample Size for Spontaneous Combustion of Used Tire Chips for Tire Chip Density of 400 kg/m^3 (Sugawa 1993)

3.3 SCRAP TIRE STORAGE GUIDELINES

The majority of the states have imposed regulations that require tires to be processed (cut, sliced and shredded) prior to landfill. Some of the states allow for storage (above ground) of shreds at landfills. In most States, whole tires are discouraged from landfills either through legislation or through high disposal fees. Texas has regulated scrap tire disposal under specific provisions of solid waste or other laws. At the National level, STMC has guidelines for the prevention and management of scrap tire fires. These guidelines are very exhaustive and a brief description of each of the topics is given below (STMC 1997).

1. *Pre-fire plans*: Every storage site needs to be well equipped to meet an eventuality of fire. They should have all information about site size, lay-out and composition. The condition of roads and accesses near the storage site should also be considered to avoid difficulties in the commuting of fire-prevention units. Pre-fire plans should contain all information about the current emergency contacts at local, state and federal levels. Videotaping facility should also be available to record an incident of fire, for further analysis. All this information may be included in an Information Management and Request Tracking system.

2. *Fire-prevention*: The common elements of fire-prevention in tire storage sites are design of the tire storage facility, site security and fire department access to the site, determining the water supply requirements and maintaining professional relations with site owners. The fire departments need to have information about any illegal dumpsites in the surrounding area. A brief summary of the STMC requirements for design of storage sites is presented in this context.

    a) Tire piles should be limited to 20 feet in height with a maximum perimeter of 250 feet by 20 feet. The edge of the piles should be at least 50 feet from the perimeter fence, and that area should be clear of debris or vegetation. Since tires tend to slide down from the sides of the pile and close off the fire breaks, all interior firebreaks should be at least 60 feet wide.

    b) An area extending 200 feet from the outside perimeter of the piles should be totally void of vegetation. All exposures, including buildings, vehicles or flammable materials should be at least 200 feet away from the tire stockpiles. Piles or storage racks should not be located near or below power lines.

    c) Scrap tires should not be stored on wetlands, flood plains, ravines, canyons or on steeply graded surfaces. Ideally, the site should be flat with concrete or hard packed clay surface designed to capture and contain water run-off.

3. *Size-up*: It is necessary to identify the dangers to civilians and fire fighters in the case of a fire. The extent and rate of spread of the fire is to be assessed. The location of nearest buildings, transportation routes and other utilities needs to be predetermined. Recognition of the immediate environmental effects is essential. An estimate of the need for personnel, additional resources and apparatus should be prepared.

4. *Establishing control*: Sectoring essential facilities such as water supply and information and communications is essential. Effective communication should exist between firegrounds, and mutual aid companies. Fire suppression units have to be installed to curb the fire in the initial stages.

5. *Health and Safety*: The health and safety issues include establishing appropriate levels of protection for the operating personnel, rehabilitating and rotation of employees, and safe methods for using firefighting and earth moving equipment. An understanding of the hazardous nature of emissions from scrap tire fires is very essential. Dangers posed by rodents, and snakes in the tire piles also have to be recognized.

6. *Suppression tactics*: This topic discusses the tactics and strategy to be followed in the case of a fire. Protection of buildings, fire fighting equipment and unburned tires is needed, despite the knowledge of potential “hot spots” and fire spread pattern.

7. *Environmental concerns*: A complete knowledge on tire composition, the tire decomposition products, the mechanism of fires and scrap tire burn characteristics is very essential. In this context, the mechanism of fire in a tire stockpile is discussed in the following section. The environmental priorities of fire departments also play a major role.

8. *Public relations and information*: There is a need to maintain an information distribution system, which responds to the queries of reporters and press.

3.4 REGULATION OF SCRAP TIRE ACTIVITY IN TEXAS

An evaluation of Texas waste tire activities was made based on information collected through interviews with TCEQ personnel. In 1989, SB 1516 was passed where Texas first required scrap tires to be at least quartered within 60 days of receipt at a disposal site. In 1991, SB 1340 established the Texas Natural Resources Conservation Commission (TCEQ) waste tire program. This program expired on December 31, 1997 and gave way to a free enterprise system for scrap tire activity. Under the Texas waste tire program, a $2.00 per tire fee was imposed upon retail sales of new passenger and motorcycle tires and these funds were diverted to a tire recycling fund to pay qualifying processors 85 cents for every 18.7 pounds of tire shreds produced. In 1993, a change was made to this fee structure where SB 1051 imposed a fee of $3.50 on truck tires and tires exceeding 17.5 inches in diameter to a maximum of 25 inches in diameter.

In 1995, SB 776 made substantial revisions to the program. Some of the salient features of this bill are listed below.

- A $1 fee was assessed on the sale of "good used tires" and a $3.50 fee on the sale of new agricultural tires 17.5 inches diameter or greater.

- Reimbursement to waste tire processors was reduced to 80 cents per 18.7 pounds of scrap tires shredded unless they have 100% recycling, for which they received 85 cents per tire.

- Processors were required to recycle their tires by sending them to legitimate end users in order to be reimbursed.

- The size of tire shreds was specified to be minus 2 in. x 2 in. unless they have a viable contract with a legitimate end user that required a different size.

- Applications and registrations were required for recycling facilities that make products (including crumb rubber) from scrap tires.

- Texas established a $2 million fund for scrap tire recycling facility construction grants. These grants were available in 1996 and 1997.

- Applications and registrations were required for energy recovery facilities that used scrap tires for fuel. For FY 1996, established a $4 million fund to provide grants to energy-recovery facilities that burn whole tires and a $2 million fund to provide grants to energy recovery facilities that burn scrap tire shreds. For FY 1997, energy recovery facilities were paid 80 cents per tire until the money ($6 million) has been reimbursed.

- The generators may not be charged a fee by the transporters who pick up their tires.

- The disposal of any whole tire that is eligible for reimbursement, or any shredded tires into a landfill, was prohibited.

Once the waste tire program expired in December 31, 1997, no fees were collected. However, generators were allowed to charge a market-driven fee at their discretion to cover the cost of managing waste tires. Since January 1, 1998, entities that generate waste tires are responsible for proper disposal. Registered transporters continue to complete manifests for waste tires and transport waste tires to approved disposal sites such as processor facilities or landfills. The remaining funds available with TCEQ is being used for clean up of illegal and discarded piles. The State still require that processors demonstrate an ability to process and sell the tires taken in, and if not, they face shutting down of their operations. While the TCEQ continue its efforts to recycle the 19 million waste tires generated each year in Texas, the program will no longer provide free waste tire collection or reimbursement for tire shredding and recycling. A comparison of the Texas Waste Tire Program before and after December 31, 1997 is given in Table 3.1.

Table 3.1 Comparison of Texas Waste Tire Program Before and After 12//31/1997.

Until December 31, 1997	Since January 1, 1998
Consumers pay a fee with purchase of new tires	No waste tire fee is collected by tire dealer to be sent to the Comptroller's Office. Tire dealers may charge a fee at their discretion.
Generators receive free collection of waste tires.	No free collection of waste tires. Generators must pay for disposal.
Tires prohibited from landfills.	Tires can be disposed of in landfills if they are split, quartered or shredded.
TCEQ registers transporters, processors, storage sites, recycling and energy recovery facilities	No change
Manifest system used to track disposal to enforce against illegal disposal by generators and transporters	No change
Illegal site (Priority Enforcement List (PEL)) cleanup suspended until September 1, 1997, then sites will be remediated using competitive bids.	PEL site clean up awarded through competitive bids. New sites will be referred to enforcement.
Reimburse processors $ 0.80 per tire for collection, shredding and recycling. Reimburse energy recovery facilities $0.80 per tire for burning whole tires and $0.40 per tire for burning shreds.	No reimbursements by TCEQ.

Besides, the generators, transporters and storage facilities of waste tires have to follow the certain guidelines imposed by TCEQ, for the effective management of scrap tires. An overview of these guidelines is presented in the following section.

3.5 TCEQ REQUIREMENTS FOR MANAGEMENT OF USED TIRES

TCEQ manages the scrap tire activity in the state of Texas through a series of regulations aimed at each entity of participants. These entities must comply with local ordinances that may be more stringent. Prior to disposal, whole tires may not be commingled with any other type of scrap material (TCEQ 1999). A brief overview of TCEQ regulations for each entity, are listed below.

3.5.1 Generators

- Generators storing more than 500 scrap tires must register.

- Registered generators may store up to 2,000 tires. Storage over 500 scrap tires must be in trailers or other enclosed portable and lockable containers. Tires stored outside must be monitored for vectors at least once every two weeks.

- Generators must document the removal of all scrap tires using manifests, work orders, invoices or other records.

- Good used tires must be sorted, marked, classified, and arranged in an organized manner for sale.

- Generators may transport scrap tires between business locations or to an authorized facility without a transporter registration, but must still comply with all manifesting requirements.

3.5.2 Transporters

- One time registration and no fees for registration or hauling.

- Transporters maintain records using a manifest system, and must notify the generator of any changes to the manifest.

- Registration exemptions: generators hauling own tires, MSW collection vehicles, local government vehicles, and retreaders who haul tires from customers for retreading.

3.5.3 Manifest

- A generator receives the completed manifest within 60 days after the scrap tires were transported off-site.

- The generator should notify the regional office of any transporter or authorized scrap tire facility that fails to complete the manifest, alters the generator portion of the manifest, or fails to return the manifest within 3 months after the off-site transportation.

- Originals of manifests, work orders, invoices and other documentation must be retained by the generators for a period of three years.

3.5.4 Scrap Tire Facilities

- Includes processors, balers, energy recovery and recycling facilities

- No storage site required unless storing more than 500 scrap tires.

- Annual Report required.

3.5.5 Storage Sites

- May store scrap tires or tire pieces using: outdoor piles up to 15 feet in height, and less than 8,000 square feet in area; indoor tire piles less than 12,000 cubic feet with a 10-foot aisle space between piles or bins; or enclosed and lockable containers.
- No variance for supersized piles (< 8,000 ft^2), and fire lanes and setbacks must be at least 40 feet.
- Scrap tires must be split, quartered, or shredded within 90 days from the date of delivery.
- The scrap tire storage site must have fire hydrants or a firewater storage pond with large capacity dry chemical fire extinguishers.
- Record keeping: Daily log, manifests, and an annual report. Closure cost estimates must be prepared by a professional engineer.

3.5.6 Landfills

- Any permitted municipal solid waste landfill site may store or process whole tires or tire pieces.

- Only split, quartered or shredded tires may be disposed of in a landfill, no whole tires.

- Monofill Permit Required: No underground disposal or placement of tires or tire pieces into a tire monofill without a permit. A separate permit is not required within the permit boundary at a permitted municipal solid waste landfill site.

3.5.7 Land Reclamation Projects

- Notification with approval in writing required including: location map, legal description, approximate volume of tire pieces, approximate period of time of the project, and the method of placement and commingling.

- Public and local government notification required with application.

- Design, affidavit and closure certification must be prepared by a professional engineer.

- Design: less than 50% of tire material by volume, no whole tires, 18 inch cover, cannot rise above natural grade. All tires used to fill land must be split, quartered or shredded. Whole tires cannot be placed below ground.

- The owner/operator of the project must register as a scrap tire facility if shredding is conducted on site.

CHAPTER 4
CASE STUDIES ON SCRAP TIRE PROJECT FAILURES

4.1 INTRODUCTION

By 1997, three of the 70 installations of tire chip fill applications in the US experienced problems associated with exothermic reactions that generated fumes and even burning of tires. Federal Highway Administration (FHWA) commissioned a study to determine the causes of these failures (Humphrey 1996). Thirty states responded to a survey conducted by FHWA on tire shred fills and out of these states, only eight states (Colorado, Kentucky, Maine, Minnesota, North Carolina, Vermont, Washington and Wyoming) indicated the presence of tire shred fills. In addition, the author was aware of two other fills in Oregon and Virginia. The three projects were primarily constructed with tire shreds from steel belted tires and the fills varied in thickness from 9 inches to 20 feet. In general, these tire-shred fills were covered by at least 2 ft. of mineral soil. Humphrey (1996) listed the following possible mechanisms of initial exothermic reactions in tire shred fills.

- Oxidation of exposed steel wires: Oxidation (corrosion) of steel is an exothermic reaction and it requires the presence of electrical continuity across the mass, oxygen and water. The rate of corrosion is proportional to temperature, pH of the environment and the presence of salts and organic products. The heat energy released during oxidation is 2623 Btu for every pound of iron oxidized. Tires contain approximately 10% steel by weight. When this steel undergoes oxidation, the resulting chemical reactions (Equation 2.1) are highly exothermic releasing about 341 kJ/mole of Fe.

  $$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3 + \text{heat} \qquad \text{Eq 4.1}$$

  Humphrey calculated the volumetric heat capacity as 25 Btu/(°F ft^3) and showed that if heat loss was neglected, oxidation of 0.095 lb of steel wire is required to raise the temperature of 1ft^3 of tire shred fill by 10°F. Humphrey used these calculations to suggest that oxidation of steel belts may cause sufficient heat build-up provided the reaction occurs quickly enough for heat to be generated at a rate faster than it is dissipated.

- Oxidation of tire rubber

- Microbes consuming exposed steel belts or generating acidic conditions - Microbes enhance the process by generating favorable acidic conditions. Sulfur oxidizing bacteria oxidize sulfur resulting in the formation of sulfuric acid, which in turn lowers the pH. A pH value of 4 or less would enhance the process of corrosion of steel belts.

A summary of the three case studies based on information obtained from Humphrey (1996) is given in Table 4.1 below.

Table 4.1 Details of Projects With Problems Attributed to Scrap Tire Use

	Ilwaco, Washington	**Garfield County, Washington**	**Glenwood Canyon, Colorado**
Purpose of Use	Embankment landslide repair	Embankment material	Retaining wall backfill
Location	SR 100 Loop Rd. near Fort Canby State Park	Falling Spring Rd. near Pomeroy, Approx. 50 ft. embankment on culvert	Hanging lake restoration & comfort station
Design	4ft rockfill blanket @ bottom of slide (3 in. crushed rock) Tire shred layer (up to 26ft deep) above rockfill blanket 3ft max. lift thickness compacted min. 3 passes of 70,000 lb bulldozer Tire shreds 4-6 in. x 2 in. Geotextile on top & slopes 4ft crushed rock over geotextile	40-60 ft. tire shred fill w/12-18 in. lifts compacted with number of passes decided by operator. 2 types of shreds used: hammer mill shreds (up to 12in. long) & shearind mill shreds (up to 10in. long). 4-7ft. pit run gravel over tire fill	70 ft. retaining wall made of 2x4x1.33 ft. tore blocks made of tire rubber + latex Backfill reinforced with geogrids. Backfill covered by 2 ft. of earth followed by topsoil/compost mixture.
Construction Date	Paved Oct. 31, 1995	Fall '94 – Spring '95	Fall 1994
Problems	12/20/95: Longit. crack in pavement Jan 03, 1996: Steam & heat released from embankment Jan 17, 1996: Monitoring began. No clear pattern of temp. variation. Temp. ranged from 60-160 °F. Oct 31 '95-Feb 22, '96: 0.6 in. of settlement Mid Feb '96: Evidence of increasing reaction Early March '96: Liquid petroleum products emerged from base of tire shred fill	July 6 '95: Flash flood caused waterlogging of embankment upstream. Oct 7, '95: Passerby reported smoke coming from fissures in the fill, later found out to be steam, not smoke. Oct 7 '95-Jan 17 '96: Continued steam vent Jan 17, 20 '96: Open fires downstream of embankment. Feb. 9, '96 no flames but more steam & smoke released	Summer '95: Steam observed at several locations

For construction procedures involving tire chips in the future, Humphrey (1996) suggested that at least 4 feet of soil cover be provided over the tire chips, to reduce infiltration of water and availability of oxygen. It was also recommended that exposed steel belts should be minimized and larger tire shreds (around 8 inches) should be used. Extensive studies and research conducted in Maine revealed that free access to oxygen, tires chips being contaminated with petroleum, insufficiently thick top soil cover, large amounts of exposed steel are a few main causes for fire in embankments.

4.2 TIRE EMBANKMENT FIRE IN ILWACO, WASHINGTON

Tire shreds from approximately 4000 tons of waste tires, 4 to 6 inches in length and 2 inches in width, were used to repair a landslide in September of 1995. A cross sectional view of the slide repair is shown in Figure 4.1. The topsoil material contained organic matter such as fertilizer and mulch (Humphrey 1996).

A few days before December 25, 1995, initial problems began with a crack in the pavement followed by the release of steam and heat on January 3, 1996. Tests showed that there was an exothermic reaction in a concentrated area of the fill. The rate of reaction increased with time and liquid petroleum products were seen discharging form the base of the fill. Air quality tests revealed the presence of Carbon Monoxide, Hydrogen Sulfide and organic hydrocarbons in certain areas of the fill (Humphrey 1996). Testing of water samples showed the presence of Zinc and cis-1, 2-Dichloroethane in trace amounts. Soil samples tested form the affected area of the fill illustrated the existence of metals such as Lead, Aluminum, Iron, Silver and Beryllium. Subsequently, further cracking of the pavement and settlement of the fill, equivalent to 2.3% compression of tire shreds was also observed.

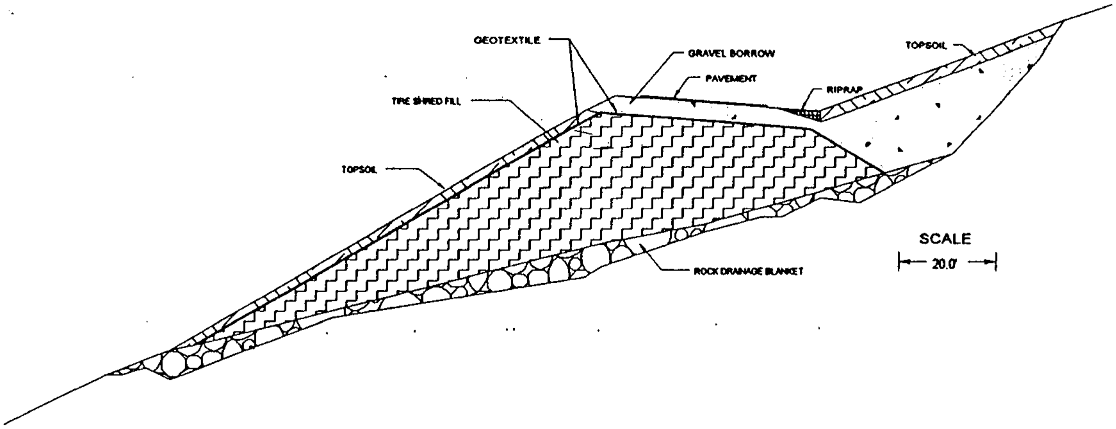


Figure 4.1 Cross Section of Tire Fill in Ilwaco, Washington (Humphrey 1996)

4.3 TIRE EMBANKMENT FIRE IN GARFIELD COUNTY, WASHINGTON

Tire chips 12 inches long and 2 inches wide, were used to construct a road embankment in the fall of 1994. Approximately 12,000 tons of embankment fill was used. The length of the embankment was approximately 225 feet, measured along the centerline of the roadway. A cross section of the embankment is illustrated in Figure 4.2. Two types of tire shreds were used. The first was produced using a hammer-mill and the second by shearing. The shreds were spread in 8 to 12-inch thick lifts and covered up with 2 to 7 feet of gravel to form the road surface.

The initial problems observed were, minor settlement in the fill (from spring 1995, through October 1995) and smoke coming out of a fissure in the fill (October 7, 1995). As time passed, open flames were seen followed by steam and smoke venting form numerous locations (Humphrey 1996). Gas analysis revealed the presence of Hydrogen Sulfide and Carbon Monoxide, which indicated that incomplete combustion of tire fill was taking place.

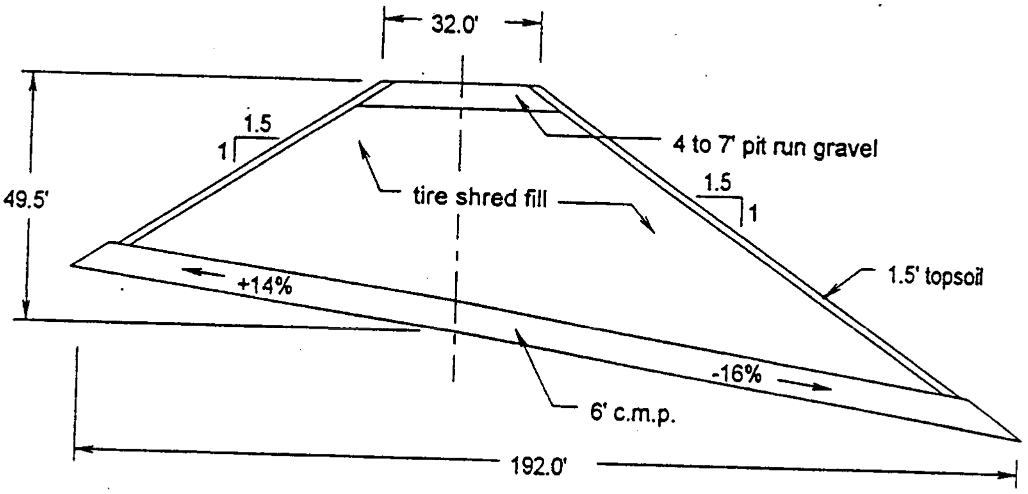


Figure 4.2 Cross Section of Tire Fill in Garfield Co., Washington (Humphrey 1996)

4.4 IDENTIFIED CAUSES OF TIRE FIRES

The potential causes identified by Humphrey (1996) for the initial exothermic reactions in the above two cases were the oxidation of exposed steel wire and the oxidation of rubber and microbes generating acidic conditions. A flood that occurred on July 6, 1995, was identified as a major source of oxygen for the fill in Garfield County. The organic matter contained in the topsoil layer used to cover the fill in Ilwaco, enhanced the oxidation of exposed steel belts. There was a rockfill drain below the fill, which also served as a source of oxygen to the fill.

Nightingale and Green (1997) investigated whether Sugawa's theory (Sugawa 1993) developed for autocombustion of tire fills could be used to explain the scrap tire fill fires in Washington. Nightingale and Sugawa used weather data from the two sites for the period when the fires were observed and plotted that data to determine where on Sugawa's plot (Figure 3.1) the data points would fall for the two sites. Nightingale's plots for Garfield County tire fill embankment and Ilwaco tire fill are illustrated in Figures 4.3 and 4.4 respectively.

Of the 70 test tire fill projects constructed in the U.S., only the three projects identified in Table 4.1 failed due to fires. An interesting feature is that these three had the largest tire fill thicknesses (upto 26 ft., 40-60 ft. and 70 ft.) of all 70 projects. This may lend credence to Sugawa's theory relating ambient temperature to critical tire fill thickness required for spontaneous combustion. Based on the data plotted in Figures 4.3 and 4.4 (Nightingale 1997), it can be seen that both Ilwaco and Garfield County project data for temperature and tire fill thickness show that they fall within the ignition zone.

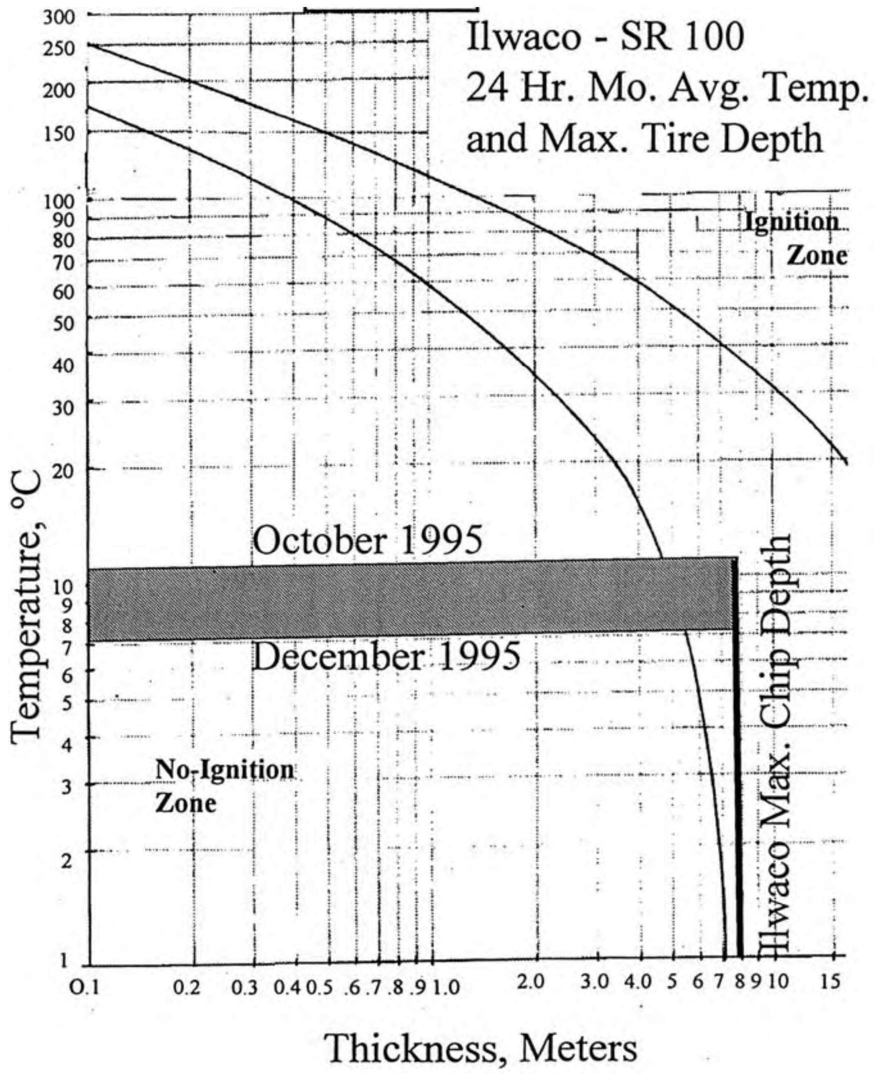


Figure 4.3 Ilwaco Data Plotted on Sugawa's Chart (Nightingale and Green 1997)

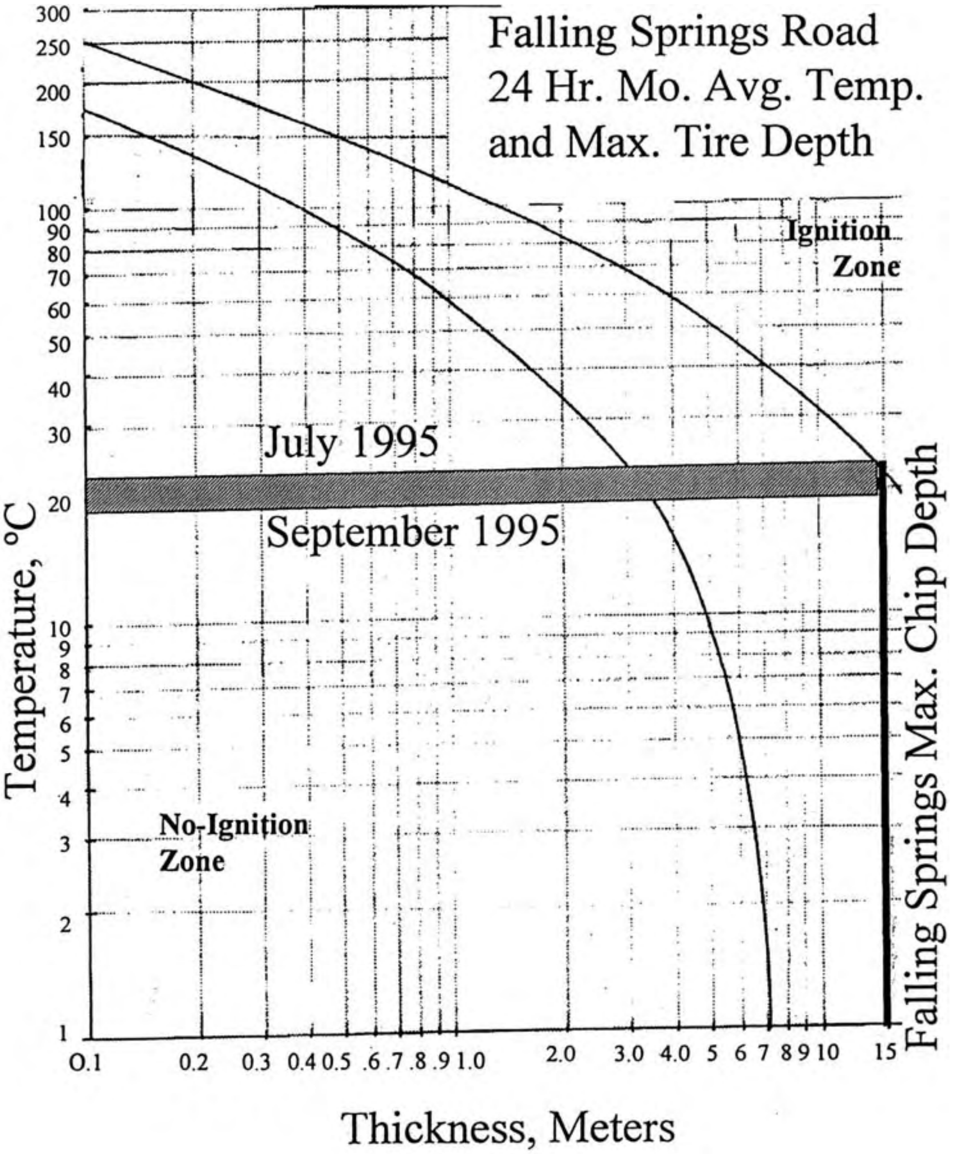


Figure 4.4 Garfield Co. Data Plotted on Sugawa's Chart (Nightingale and Green 1997)

CHAPTER 5
RECOMMENDED HIGH-VOLUME APPLICATIONS

5.1 MARINE REEFS

After evaluating the various potential uses for scrap tires, five applications were selected for further study as potential high-volume applications in civil engineering. These are marine reefs, tire bales in embankments, tire chips in embankments, rubber modified asphalt pavements and tire retaining walls.

5.1.1 Design of Model Reefs

Marine reefs are habitats for fish and other sea animals. Texas, with its vast shoreline and an abundance of lakes, is a potential market for scrap tire reefs. In 1986 and 1987, New Jersey Division of Marine Fisheries constructed a number of reefs using scrap tires off the coast of New Jersey (Myatt et al. 1989). Ten tire cascade models as shown in Table 5.1 and Figure 5.1, were tested in the waters of the Atlantic Ocean. They are listed here in no particular order.

Table 5.1 Reef Designs Tested by NJ Division of Marine Fisheries (Myatt et al. 1989)

Design	Tires per Unit	Model Details
I	25	Tire cascade ballasted with concrete
II	13	Similar to Type 1 except for the number of tires used
III	25	Tire cascade with a concrete base of size 89x89x15 cm
IV	24	Tire cascade with a concrete base of size 87x87x24 cm
V	45	Baseless tire cascade made with two inter-linked cascades
VI	45	Baseless tire cascade made with two inter-linked cascades
VII	25	Tire cascade made by placing the stack tread-down into a wooden form and concreted using steel tie-bars.
VIII	7	7 partially sliced car tires tied together as a pyramid and placed in a form so lower tires rested on a concrete base
IX	8	8 partially split car tires linked and put in a form made of two nested truck tire halves, and then concreted.
X	12	Has 12 partially split truck tires (similar to Design II)

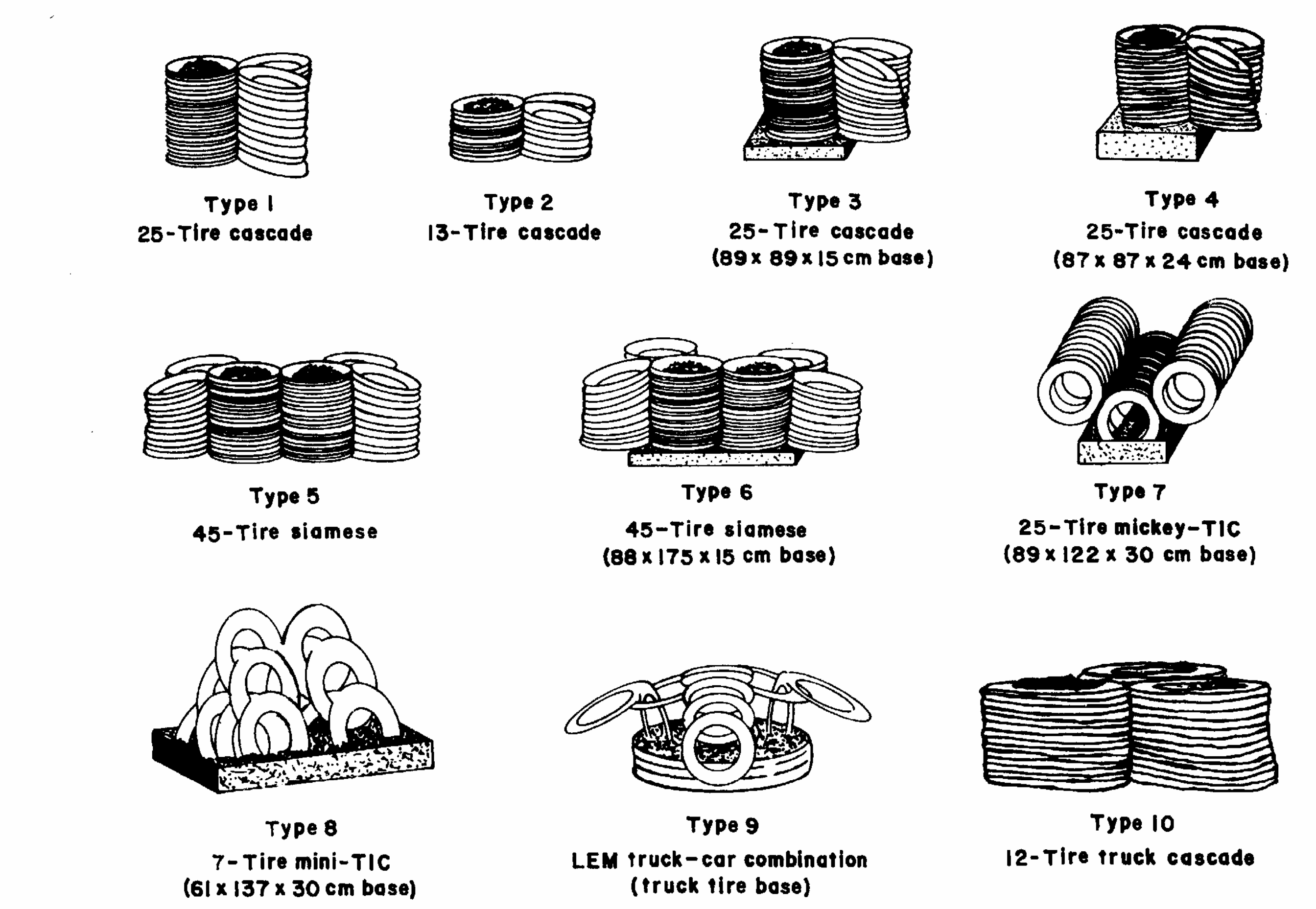


Figure 5.1 Reef Designs Tested by NJ Division of Marine Fisheries (Myatt et al. 1989)

Of these reef types, some were successful while others failed. Their success was determined based on a stability score given to each type. Table 5.2 shows a listing of key properties of each design and the weights used to calculate the total weight of the unit is given in Table 5.3.

Figure 5.2 Stability Scores for Reef Designs Used by NJ Division of Marine Fisheries (Myatt et al. 1989)

Table 5.3 Parameter Values Used to Calculate Weight of Reef Units

Construction Item	Weight in air	Submerged weight
Concrete	2257 kg/m^3 (140.9 lb/ft^3)	1241.4 kg/m^3 (77.5 lb/ft^3)
Car tire	9.3 kg (20.6 lb.)	1.4 kg (3.1 lb.)
Truck tire	39.2 kg (86.5 lb.)	5.9 kg (13.0 lb.)

5.1.2 Performance

After the installation of reef units, there performance was evaluated using a stability score (0 to 100%) based on the following. Tire units meeting the above requirements were expected to be stable at depths of 18.3 m and 24.4 m.

- 0 points for units not found after the observation in July 1987 and for units that have moved beyond a 91.4-m radius of their point of deployment.

- 5 Points for units that moved within 91.4 m of their point of deployment.

- 5 points for units that were found jammed against other units.

- 10 Points for units that did not move from their original point of deployment.

Table 5.4 summarizes the total scores that were allotted to the ten test types. The following inferences can be drawn from the scores that were obtained. These are illustrated in Figure 5.2.

- In general, reef units with increasing submerged unit densities showed better stability. The range for submerged unit densities for the successful tire types that were identified by a stability score of 100%, were 266 to 499 kg/m^2.

- Stability increased with increasing ballast-to-rubber ratios. Those units with a minimum 10 kg of concrete per 1 kg of rubber had 100% stability scores.

- Higher ballast-to-tire ratios also increased stability, for units with 12-42 kg per tire.

If not properly ballasted with concrete, tire reef units could drift towards the beach. The North Carolina Department of Marine Fisheries (NCDMF 1997) found that installation of artificial reefs, similar to those used in New Jersey, would cost about $3.50 per tire (inclusive of transportation from tire disposal site to the installation stage). The tires would cost about $1 per running mile to be transported from the stacking center to the site of construction. This is calculated for a heavy truck that could carry 1200 to 1500 tires per load. Therefore, this is a costly alternative to the conventional reef material such as concrete debris and rock. But scrap tire reefs are expected to give longer life and would also provide a solution to the scrap tire problem in the United States.

Table 5.4 Summary of Stability Test Results for Reef Units (Myatt et al. 1989)

	Unit Type & Description	Units Tested	Found in-Place	Found Moved	Found Jammed	Not Found	Stability Score(%)
1	25-Tire cascade (baseless)	6	0	0	0	6	0
2	13-Tire cascade (baseless)	6	0	6	0	0	50
3	25-Tire cascade (35x35x6 in. base)	6	3	3	0	0	75
4	25-Tire cascade (34x34x12 in. base)	6	6	0	0	0	100
5	45-Tire cascade (baseless)	6	1	3	2	0	41.7
6	45-Tire siamese (35x69x6 in. base)	6	6	0	0	0	100
7	25-Tire mickey-TIC (35x48x12 in. base)	6	6	0	0	0	100
8	7-Tire mini-TIC (24x54x12 in. base)	6	6	0	0	0	100
9	LEM 8-tire combination (truck tire base)	2	2	0	0	0	100
10	12-Tire cascade (baseless)	3	1	2	0	0	66.7

5.1.3 Use of Fly Ash as Reef Ballast

In States such as Texas, in east and west Texas in particular, where the cost of aggregates can be high or where there is a scarcity of aggregates for making concrete, hydrated fly ash can be used in place of concrete as the ballast material. Tests on fly ash showed that hydrated fly ash can gain a specific gravity of 1.85 at 20 % hydration water, which is comparable to the density of concrete (Nash et al. 1996). Table 4.5 shows the variation of specific gravity of fly ash with percent hydration.

Table 5.5 Specific Gravity of Hydrated Fly Ash vs. % Hydration Water (Nash et al. 1996)

Hydration Water Content (%)	Specific Gravity
20	1.85
40	1.4
60	1.13
100	0.8

For fly ash with a specific gravity of 1.85 (at 20 % hydration water), calculations were done to find out if the minimum submerged densities, minimum ballast-to-tire and ballast-to-rubber ratios could be achieved using hydrated fly ash as ballast. A comparison of these values using fly ash and concrete has been made in Table 5.6 for the reef units that achieved a stability score of 100.

Table 5.6 Comparison of Values using Concrete and Fly ash as ballast in Reefs

Reef Unit	**Submerged Density (kg/m^3)**		**Submerged Ballast-to-Rubber Ratio**		**Submerged Ballast-to-Tire Ratio**	
	Fly Ash Ballast	**Concrete Ballast**	**Fly Ash Ballast**	**Concrete Ballast**	**Fly Ash Ballast**	**Concrete Ballast**
IV	268.17	335.3	7.35	10.6	10.29	13.3
VI	212.156	266.6	6.4	9.3	8.97	11.6
VII	306.26	386.9	7.75	11.1	10.85	14.1
VIII	388.38	499.0	22.77	30.6	31.89	41.4
IX	230.286	293.6	12.0	13.37	18.72	20.9
Required Minimum*	275		10	10	11	

* - Established based on New Jersey Field Experiments

Considering the performance of New Jersey reef study and results presented for fly ash ballast as presented in Table 5.6, the following inferences can be made (Myatt et al. 1988).

- The minimum requirement of submerged density for a reef to stay in place is 275 kg/m^3. Types VII and VIII meet this requirement when fly ash is used as ballast.
- The minimum ballast-to-rubber ratio required with concrete ballast is 10kg of concrete per 1kg of rubber. Types VIII and IX satisfy this requirement when fly ash is used.
- A minimum of 11kg of concrete per tire is required as the submerged ballast-to-tire ratio for a reef to be in place. The types VIII and IX meet this minimum when fly ash is used as the ballast material.

Taking the three inferences into consideration, it can be said that reef type VIII, shown in Figure 5.3, meets all the minimum requirements for a reef to stay in place and hence this type of reef is recommended for use. The type VIII reef requires 7 tires for a single unit.

The current level of fly ash production is believed to be in excess of 50 million tons in the United States. Type C Fly ash would cost about $10 per ton (including material and transportation costs) to any area in West Texas. Handling of fly ash would be easy due to its low unit weight of 1100 - 1500 kg/m^3. Therefore, use of fly ash as ballast is much cheaper than Portland cement concrete ballast in areas where fly ash is readily available.

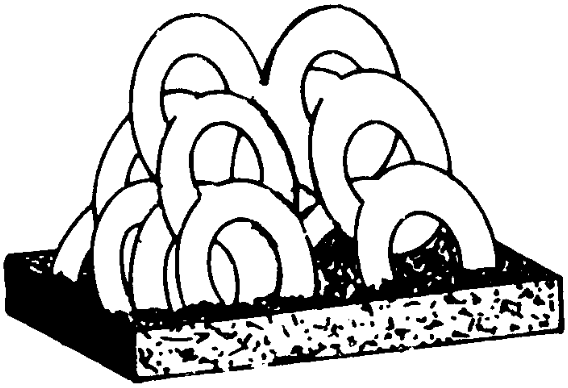


Figure 5.3 Type VIII Reef Used by NJ Division of Marine Fisheries (Myatt et al. 1989)

5.2 USE OF WHOLE TIRES IN TIRE BALES

5.2.1 Introduction

Tire bales are compressed tires wrapped in steel wire and used as a whole unit for construction purposes. The Encore® baler is a vertical down stroke baler that compresses approximately 100 passenger and light truck tires into a uniform block measuring 30" X 50" X 60”. Unlike the expensive shredding systems, the baler is relatively inexpensive, has virtually no down time and has very low maintenance costs**.**

Potential uses for tire bales include sound barriers along highways, impact barriers for highways or racetracks, retaining walls, animal containment areas, grain storage, windbreaks, fencing, fish farming, hurricane walls, mud slide control and erosion control (Encore Systems, Inc. 1999).

Tire bales offer many benefits. Baling tires can save space through volume reduction reaching up to 4:1. As shown in Table 2.1, in the southwest U.S., shredding tires into chips may cost around $40 per ton. A tire bale consisting of 100 tires can be produced for around $15-20. In addition to the cost advantages, tire bales are easily handled (stacked) when used in construction activities compared to tire chips where mixing with soil and compaction is needed. The baler and two men are capable of making from four to six bales an hour on a steady basis (Encore Systems, 1999). The completed bales are easily handled with a forklift, front-end loader, logger's clam or grappler. Because of the uniformity of the bales, they can be easily stacked.

Tires in baled (compressed) form do not hold the water and therefore pose no threat to public health due to mosquitoes. Because of the density of the bale, the decreased surface area, and the lack of air, the fire hazard is also greatly reduced. Many successful projects have already been completed using the bales. These projects include impact barriers, erosion control, land reclamation, horse training arenas, fences, and dam construction. In some uses, the bales are painted or coated with soil, shotcrete, plastic, foam or rubber compounds. Coating the bales improves the aesthetics and creates a barrier to extend the integrity of the wire almost indefinitely.

5.2.2 Project Background

Tire bales have been successfully used to construct a retaining wall three to four feet high along the Pecos river bank near Lake Carlsbad, New Mexico. The project began in September 1997 and was completed by May 1998. Approximately 700,000 recycled scrap tires were used in the form of bales, each weighing approximately one ton, to stabilize 4400 linear feet of the east bank of Pecos River in Lake Carlsbad. Lake Carlsbad, which is a popular year-around recreational area in New Mexico, has been undergoing serious erosion problems due to river currents and recreational use. Figure 5.4 indicates the destructive effects of wave action before corrective action was taken by the Environment Department of the State of New Mexico.

Figure 5.4 Erosion Damage in Lake Carlsbad, New Mexico (NMED 1999)

After reviewing several design options, the City of Carlsbad opted to construct a concrete retaining wall to provide bank protection in the area. The design, which is illustrated in Figure 5.5, shows how waste tire bales were used.

5.2.3 Construction

The baler shown in Figure 5.6 was used to convert 100 passenger tires into one bale in 10 minutes. Each bale weighed 2000 pounds and had dimensions of 30x50x60 inches. Each bale was then wrapped in a wire mesh (Figure 5.7) and placed on a 10-inch thick reinforced concrete base while the base concrete is still wet. The bales were lowered on to the wet cement using an excavator and chains, as shown in Figure 5.8. Afterwards, the tire bales were encapsulated in cement, stucco or some other facing material (Figure 5.9). The partially completed erosion control retaining wall is shown in Figure 5.10 illustrating the 8-inch thick concrete wall outside the tire bales, which is covered by a rock veneer of approximately 2.5 inches thick. The cost of baling 100 tires into a one-ton bale was estimated at $0.10 per tire. The cost of transporting waste tires to the construction/ baling site was approximately $1 per running mile for a truckload (approximately 1200 to 1500 tires).

Figure 5.6 Portable Tire Baler (NMED 1999)

Figure 5.7 Bale Wrapped in Wire Mesh Before Encapsulation in Cement (NMED 1999)

Figure 5.8 Placement of One-Ton Tire Bales onto Concrete Base (NMED 1999)

Figure 5.9 A Tire Bale Partly Encapsulated in Cement (NMED 1999)

Figure 5.10 Partially Completed Retaining Wall Containing Tire Bales (NMED 1999)

5.3 USE OF TIRE CHIPS IN EMBANKMENT CONSTRUCTION

During the last decade, over 70 test projects were constructed where scrap tire chips were used in embankment construction. All projects except three have performed at least adequately. All three failed projects, which were highlighted in Chapter 4, failed due to spontaneous combustion of the tire fill. A number of studies, most notably the work done by Humphrey (1996) and Nightingale and Green (1997) investigated the causes of these failures. Based on his forensic studies, Humphrey (1997) published design guidelines to minimize internal heating of tire shred fills which were summarized in Chapter 4. It is the belief of this research team that these design guidelines, combined with Sugawa's findings on critical tire mass would form a solid foundation for further tire fill embankment construction. Based on the Frank-Kamenetskii thermal ignition theory, Sugawa (1993) showed that, in the case of a tire shred fill, depending on the ambient temperature, there exists a critical size of the adiabatic tire shred mass that will decide whether the mass will generate spontaneous combustion. Based on this approach, Sugawa developed a series of charts relating tire stockpile size to ambient temperature and identified ignition and no-ignition zones in those charts. These charts can be used as guidelines to design new tire shred fills. However, more research is needed including additional long term monitoring of test projects to verify the validity of these design guidelines.

The big question that needs to be answered is how the supply of oxygen to the tire mass and the presence of organic matter could be minimized over the life of an embankment fill. During the life of a roadway embankment, which may span many decades, the pavement is subjected to cracking that would take water and oxygen into the embankment fill. Additional research needs to answer the questions on how much effect this would have on tire and steel oxidation, and the effectiveness of measures that could be taken to minimize the effect. Two such measures would be the provision of a soil cap several feet thick, over the tire fill, and the use of geotextiles.

The two recent projects were constructed in the TxDOT El Paso District using scrap tires in roadway embankments. In one project, 100% scrap tire chips were used to construct the embankment where the tire chips were encased in a geotextile. The cost of this installation was reported to be $20 per cubic meter of fill. In the other project, tire chips blended with soil were used as the embankment material. The cost of this construction was reported to be $16 per cubic meter of fill. The cost of a traditional embankment using locally available soil was reported to be $5 per cubic meter. This shows that both types of scrap tire embankments are not cost effective.

5.4 USE OF ASPHALT-RUBBER IN PAVEMENTS

TxDOT has used recycled tire rubber in two types of pavement applications: as a binder for seal coats, and as a binder for hot mix asphaltic concrete (HMAC). The industry term for recycled tire rubber for use in asphalt applications is Crumb Rubber Modifier (CRM).

The use of CRM in seal coat applications has increased significantly since it's first application in Arizona (1967) and Texas (1976). Since then more than 20 TxDOT districts have places seal coats containing CRM. TxDOT typically uses two binder types containing CRM for seal coats.

One binder is AC-15-5TR, composed of an AC grade asphalt containing a minimum of 5% CRM as a polymer modifier. TxDOT statistics indicate that in fiscal year 2000, over 40 percent, by volume, of seal coat binder used was AC-15-5TR.

TxDOT also uses asphalt-rubber in seal coats. Asphalt-rubber is a standard product, described by ASTM specifications, generally requiring a minimum of 15% CRM. It is asphalt-rubber that saw its first TxDOT use in 1976. The use of hot rubber seal coats increased due to the federal mandate imposed by the Inter-Modal Surface Transportation Efficiency Act of 1991 (ISTEA). However, at the time, hot rubber seal coats cost as much as two to three times more than a conventional seal. The performance of hot rubber seals has been satisfactory. When interviewed by the authors regarding the effectiveness of hot rubber seal coats, a large majority of TxDOT maintenance personnel who had experience with it indicated they would use asphalt-rubber if it were cost competitive with conventional seal coat binders. Asphalt-rubber seal coats have also provided excellent service as underseals, primarily as a stress-absorbing membrane to reduce reflective cracking. As is the case with any seal coat operation, success depends a lot on material selection and construction practices. The performance of hot rubber seals often has exceeded that of conventional seals. The costs of asphalt-rubber seal coats have come down significantly over the years.

Epps (1994) reported data he collected from Texas where in 1990, a conventional seal cost $0.48 per square yard and an asphalt rubber seal cost $1.14 per square yard. This shows a significant difference (over 250%) in cost between the two options. The same study reported underseal costs as $3.20 per square yard for conventional materials and $4.25 for rubber asphalt. Data recently collected from TxDOT indicate that the difference between cost of conventional and asphalt-rubber seals has reduced significantly.

In 1999, the Rubber Pavement Association (RPA) published a study conducted jointly by Oregon State University and University of Nevada at Reno, which specifically addressed the economics of using tire rubber in asphalt applications (Hicks et al., 1999). This is the most comprehensive economic analysis done to date on the subject of economic viability of asphalt-rubber. Since there was ample evidence of the enhanced performance from the use or asphalt-rubber, they performed probabilistic life-cycle cost analyses both for hot rubber seals and asphalt-rubber hot mix by incorporating both agency costs and user costs. Data collected from TxDOT was included in the analysis and the three seal coat alternatives included were seal coat using neat asphalt cement binder, polymer modified binder and asphalt-rubber.

Table 5.7 Summary of Probabilistic Life-Cycle Cost Analysis (Hicks et al. 1999)

Agency	Comparison Options	Approximate Percent Time Asphalt-Rubber Alternative is More Cost Effective
Texas DOT	Neat Asphalt Seal Coat vs. Asphalt Rubber Seal Coat	5
	Polymer Modified Binder Seal Coat vs. Asphalt Rubber Seal Coat	13
	0.75 in. neat asphalt cement vs. asphalt rubber friction course	99
	0.75 in. polymer modified asphalt cement vs. asphalt rubber friction course	95
	2 in. thick gap-graded conventional hot mix vs. asphalt-rubber hot mix	80
	2 in. thick conventional dense-graded hot mix vs. asphalt-rubber hot mix	50
	2 in. thick gap-graded polymer-modified hot mix vs. asphalt-rubber hot mix	36
Caltrans	Conventional Seal Coat vs. Asphalt Rubber Seal Coat	20
California Cities and Counties	Polymer Modified Binder Seal Coat vs. Asphalt Rubber Seal Coat	40

5.5 USE OF WHOLE TIRES IN RETAINING WALL CONSTRUCTION

Whole tires have been used in retaining wall construction in several instances. Tires were used to construct retaining walls with the help of either ballast or soil reinforcement, or both (Jayawickrama et al., 2000). The most notable of these applications is the ECOFLEX® system developed by SULCAL Construction, Pvt. Ltd. of Australia. These retaining wall systems are built on reinforced earth, and the company projects a life expectancy of 100 years provided the tires are not subjected to combustion. In addition, retaining walls were constructed by the United States Forest Service in Northern California and in Santa Barbara. These two projects in the United States report a cost in the range of $13 to $30 per square foot of retaining wall facing. Tire bales are also a possible means of constructing retaining walls. Retterer (2000) conducted a detailed analysis for design of retaining walls using tire bales. A comprehensive investigation of the use of whole tires in retaining wall construction was conducted in TxDOT research project 0-1876 and therefore, readers are referred to that research report for additional information. (Jayawickrama et. al. 2000)

CHAPTER 6
ECONOMIC ANALYSIS

In the previous chapters, information relating to cost of using scrap tires in transportation test projects were highlighted. It could be seen from those numbers that scrap tires are not competitive with conventional materials in several of the applications recommended in Chapter 5. However, these costs only included the cost to the agency that constructed the test projects and did not consider the benefits of using scrap tires to society in general. In this chapter, a benefit-cost analysis framework has been developed to evaluate the economic feasibility of using scrap tires in transportation engineering applications.

6.1 ECONOMIC ANALYSIS FRAMEWORK

6.1.1 Benefit-Cost Analysis

Any project will result in a number of effects (benefits & costs) that can usefully be broken down into two main categories: direct effects and secondary effects. Direct effects are the effects that result from the goods and services that are directly produced by the project while secondary effects are the changes in the value of production (both increases and decreases) generated indirectly by the project (Anderson et. al., 1977). Both direct and secondary effects can be broken down into two categories: tangible effects and intangible effects. Tangible effects are relatively easy to value in dollar terms whereas intangible effects are not.

The general equations used for estimating the present value of benefits and costs are as follows:

Present Value of all benefits, $B = \sum (B_i / (1 + r)^i)$

Present Value of all costs, $C = \sum (C_i / (1 + r)^i)$

Where, B_i = Total benefits accrued in the i^{th} year

C_i = Total costs accrued in the i^{th} year

r = Discount rate

Two criteria will be used for accepting or rejecting this hypothetical commitment. These alternative criteria, and their associated decision rules are presented in Table 6.1.

Table 6.1 Criteria and Associated Decision Rules (Anderson et al. 1977)

Criteria	Decision Rule
Benefit-Cost Ratio, B/C (the ratio of the present value of benefits and costs)	Accept if B/C > 1; reject if B/C < 1 If B/C =1, Policymakers will make decision based on Intangible and Secondary benefits and costs
Net Present Value, B-C (the difference between the present value of benefits and present value of costs)	Accept if B-C > 0; reject if B-C < 0 If B-C =0, Policymakers will make decision based on Intangible and Secondary benefits and costs

In this analysis, it is assumed that with the TxDOT commitment to use scrap tires, there is a guaranteed 10-year demand for scrap tires, and at the end of each year, one test project will be constructed in the state.

6.1.2 Benefits of Using Scrap Tires

The benefits associated with scrap tire use are as follows.

6.1.2.1 Direct and Tangible Benefits: Savings in landfill space: It has been estimated that under the current system of landfilling shredded tires, the landfill cost would vary between \$13 to \$45 per ton depending on the location. In the southwestern United States, the cost is reportedly closer to \$25 per ton of shredded scrap tires. Texas generates approximately 18 million waste tires per year and at the rate of 20 lb per tire, which applies to the average passenger car tire, the savings in landfill cost by using the all of the annual generation of waste tires is \$24 million.

Savings in natural resources: The three applications identified in Chapter 5 would result in a significant reduction in the natural resource utilization in the state, particularly the use of construction aggregates.

6.1.2.2 Secondary and Tangible Benefits: Increased employment: The use of scrap tires is likely to generate new employment for baling of tires. These could be in the form of increased activity in tire processing and in the manufacture of tire bales. Long-term employment benefits would impact the employment in the area, and is outside the scope of the study.

6.1.2.3 Direct and Intangible Benefits: Less pollution as a result of a decreased amount of mining of natural resources (i.e. limestone) is one of the benefits under this category. These benefits are not estimated.

6.1.2.4 Calculation of Benefits: Steps in estimating the benefits are as follows:

$$B = B_1 + B_2 + \ldots\ldots + B_{10} \qquad (6.1)$$

Where,
B = Total present value of social benefit received out of TxDOT’s commitment
B_1 = Total Present Value of Benefits gained from 1st construction project
B_2 = Total Present Value of Benefits gained from 2nd construction project
B_{10} = Total Present Value of Benefits gained from 10th construction project

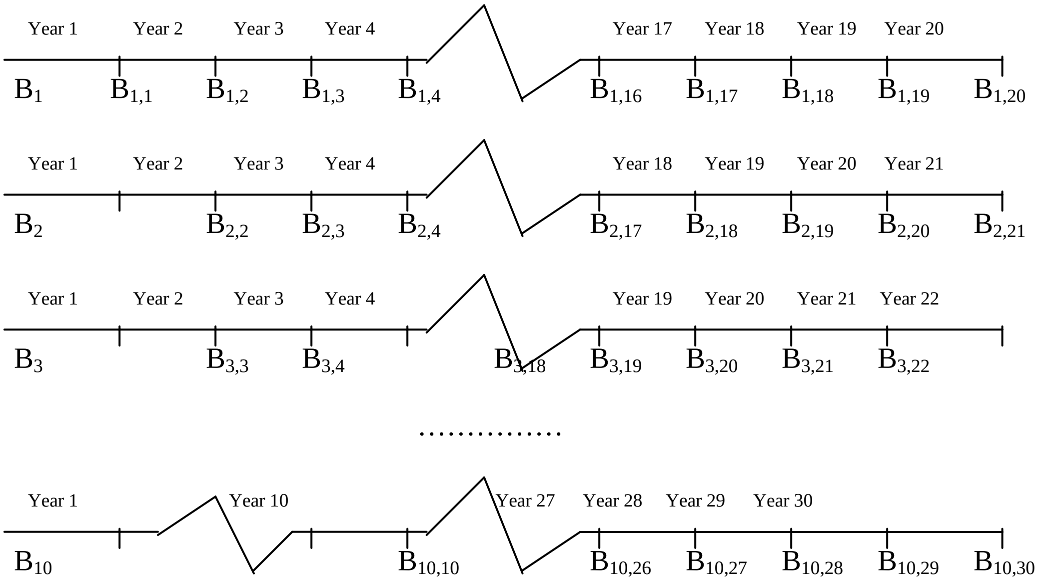
For a 20-year design life of first project,

$$B_1 = B_{1,1} / (1 + r) + B_{1,2} / (1+ r)^2 + \ldots\ldots + B_{1,20} / (1+ r)^{20} \qquad (6.2)$$

Similarly, for the second construction project,

$$B_2 = B_{2,2} / (1 + r)^{2} + B_{2,3} / (1+ r)^3 + \ldots\ldots + B_{2,21} / (1+ r)^{21} \qquad (6.3)$$

Where,
$B_{1,1}$ = Total benefits gained from 1st construction project at the end of 1st year
$B_{1,2}$ = Total benefits gained from 1st construction project at the end of 2nd year
…………………
$B_{2,21}$ = Total benefits gained from 2nd construction project at the end of 21st year
Following figure explains how society is benefited at different time from 10 projects.



6.1.3 Costs of Using Scrap Tires

6.1.3.1 Direct and Tangible Costs: The primary cost involving scrap tires is its transportation cost. It has been reported that it would cost approximately $1 per mile to transport a large truckload of tires (typically around 1200-1500 tires per load). TCEQ reports costs for transportation, shredding and storage of scrap tires in the neighborhood of $1 to $1.50 per tire.
Increased cost of construction due to incorporation of tires in construction: Due to the significant differences in designs when conventional materials and tires are used, this item is not considered in calculations. A direct comparison of costs for both alternatives was conducted in its place.
Increased maintenance/rehabilitation cost due to incorporation of scrap tires: No significant change, based on the information for the project.

6.1.3.2 Calculation of Costs:

$$C = C_1 + C_2 + \ldots\ldots + C_{10} \tag{6.4}$$

Where,

C = Total present value of social costs out of TxDOT's commitment
C_1 = Total present value of costs gained from first construction project
C_2 = Total present value of costs gained from second construction project
……………
C_{10} = Total Present Value of Costs gained from n^{th} construction project

Again,

$$C_1 = C_{1,1} / (1 + r) + C_{1,2} / (1+ r)^2 + \ldots\ldots + C_{1,20} / (1+ r)^{20} \tag{6.5}$$

Similarly, for the 2nd construction project,

$$C_2 = C_{2,2} / (1 + r)^2 + C_{2,3} / (1+ r)^3 + \ldots\ldots + C_{2,21} / (1+ r)^{21} \tag{6.6}$$

……………………

For the 10th construction project,

$$C_{10} = C_{10,10} / (1 + r)^{10} + C_{10,11} / (1+ r)^{11} + \ldots\ldots + C_{10,30} / (1+ r)^{30}$$

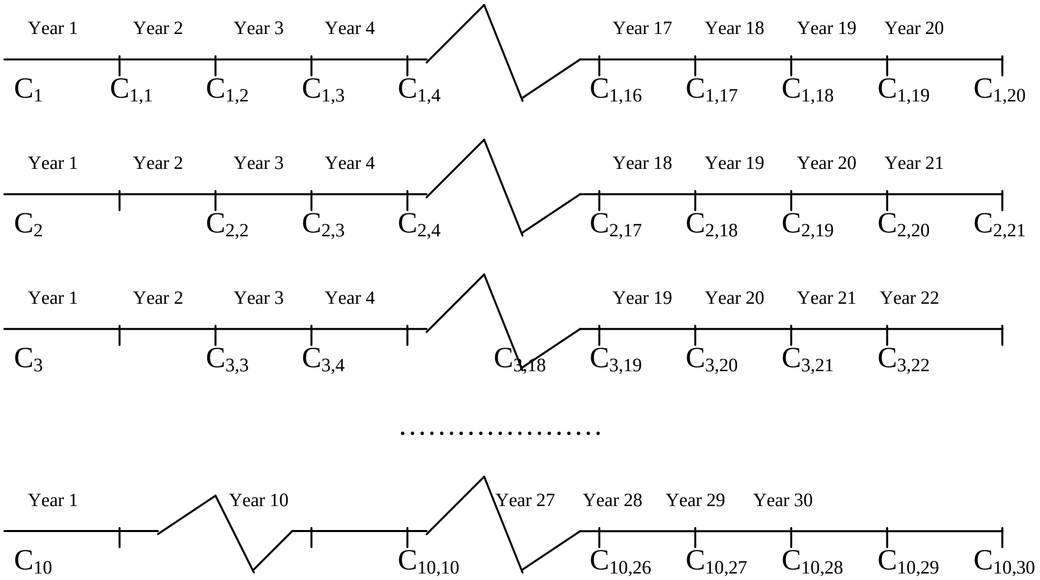
Where,

$C_{1,1}$ = Total costs gained from 1st construction project at the end of 1st year
$C_{1,2}$ = Total costs gained from 1st construction project at the end of 2nd year
$C_{2,21}$ = Total costs gained from 2nd construction project at the end of 21st year

…………………

$C_{10,30}$ = Total costs gained from 10th construction project at the end of 30th year

Following figure explains how society bears costs at different time for the 10 projects



6.2 ANALYSIS RESULTS

The economic analysis was conducted for two of the most promising applications for scrap tires; tire bales in retaining wall construction and tire chips in embankment construction. In the cost-benefit analysis, breakeven conditions were determined for both of the applications indicated above. As mentioned previously, the economic analysis assumed that TxDOT would guarantee the construct one project each year for 10 years and that each project would last for 20 years with no maintenance. It was also assumed that the maintenance cost is the same between the conventional solution and the waste tire alternative. First, the economic analysis was conducted from the standpoint of the whole society by considering the benefits as well as costs to the greater society. Subsequently, an analysis was also conducted from the standpoint of TxDOT by considering the relative costs of materials.

6.2.1 Tire-Bales in Retaining Wall Construction

For the tire bale retaining wall application, a project similar to the one constructed in Carlsbad, New Mexico, where scrap tires were used in embankment retaining walls, was considered. The conventional solution in this case was considered to be a 12-inch thick reinforced concrete retaining wall to provide soil retention and lake bank protection. The following cost information is used in the analysis.

- Total length of embankment to be constructed = 4400 linear feet
- Total height of soil retention = 8 feet
- Cost of concrete is \$40 per cubic yard
- Cost of tire bale wall (including construction) = \$30/bale
- Weight of tire bale = 1 ton
- Number of tire bales used = 7000 (100 tires per bale)
- Landfill cost for shredded tires = \$25 per ton

Total social benefits from project in year 1 = Savings in natural resources + savings in landfill volume
= 8ft x 1ft x 4400ft x (1/27) yd^3/ft^3 x \$40 / yd^3 + \$25/ton x 7000 tons = \$227,150

At 3% discount rate,
$B_1 = 227{,}150/(1+0.03) + 0/(1+0.03)^2 + \ldots\ldots + 0/(1+0.03)^{20}$
= \$220,534 (No benefits in the subsequent years of construction)

Similarly,
$B_2 = 227{,}150/(1+0.03)^2 + 0/(1+0.03)^3 + \ldots\ldots + 0/(1+0.03)^{21}$
= \$214,111

………………

$B_{10} = 227{,}150/(1+0.03)^{10} + 0/(1+0.03)^{11} + \ldots\ldots + 0/(1+0.03)^{30}$
= 169,020 So,
B = 152,573 + 148,129 + …… + 116,934
= \$1,937,635

Now, total social costs for the construction project during first year
= \$20/bale x 7000 bales = \$ 140,000

At 3% discount rate,
$C_1 = 140{,}000/(1+0.03) + 0/(1+0.03)^2 + \ldots\ldots + 0/(1+0.03)^{20}$
= 135,922 (Assumption: No additional maintenance costs due to tire use)

Similarly,
$C_2 = 140{,}000/(1+0.03)^2 + 0/(1+0.03)^3 + \ldots\ldots + 0/(1+0.03)^{21}$
= 131,963

………………

$C_{10} = 140{,}000/(1+0.03)^{10} + 0/(1+0.03)^{11} + \ldots\ldots + 0/(1+0.03)^{30}$

= 104,173
Therefore, C = 135,922 + 131,963 + ……+ 104,173
= 1,194,228

Check for economic criteria (Table 6.1): B/C @ 3% discount rate = 1,937,635/1,194,228 = 1.62
Net Present Value (@ 3% discount rate) = 1,937,635 - 1,194,228 = $743,407

Therefore, by considering the benefits to the society as a whole, the use of tire bales for retaining wall construction appears to make economic sense for the conditions assumed. The breakeven point (B/C of 1.0) for the conditions assumed for the above cost-benefit analysis was calculated to be an 8 in. thick reinforced concrete retaining wall that is 8 feet high. An application such as the tire bale retaining wall considered above also significantly helps the tire disposal problem because it used 700,000 waste tires. Based on the assumption made above, this would result in the use of 7 million waste tires over a 10-year period, which amounts to 40 percent of the annual waste tire generation in the state.

However, from the TxDOT standpoint, by taking the benefits to the environment out of the analysis, calculations showed that the breakeven point is achieved if the tire bale retaining wall is able to replace a reinforced concrete retaining wall with a thickness of 32 inches thick for the same retaining height of 8 feet.

6.2.2 Tire Chips as Embankment Material

Tire chips in embankment construction has been one of the most popular uses of scrap tires. Over 70 projects have been constructed in the United States over the years. The projects have used tire chips either exclusively or as a blend of soil and tire chips. Breakeven conditions were determined for different tire chip-soil blends. In this analysis, the cost of conventional embankment material was assumed to be $10 per cubic yard and the cost of tire chips was assumed to be $15 per cubic yard.

Using the economic analysis framework outlined in 6.1, the breakeven tire-soil blends were determined for a project where 200,000 waste tires are to be used when benefits to the whole society were considered. The results are shown in Table 6.2.

Table 6.2 Percent Tire Chips in Tire-Soil Mixture to Achieve Breakeven Conditions by Considering Benefits to the Whole Society

Embankment Volume (yd^3)	10,000	15,000	20,000	25,000	30,000	50,000
% Tire Chips in Tire-Soil Blend	58.1%	38.8%	29.1%	23.3%	19.4%	11.6%
Waste Tires Used per Project	200,000	200,000	200,000	200,000	200,000	200,000

Similar to the analysis indicated above, breakeven % tire chips was determined by only considering the interest of TxDOT. The results from this analysis are shown in Table 6.3.

Table 6.3 Percent Tire Chips in Tire-Soil Mixture to Achieve Breakeven Conditions by Considering Only the Interests of TxDOT

Waste Tires Used per Project	475,000	475,000	475,000	475,000	475,000	475,000
Breakeven % Tire Chips in Tire-Soil Blend	50%	40%	30%	20%	15%	10%
Embankment Volume (yd^3)	28,000	35,000	46,500	70,000	93,000	140,000

For the conditions assumed in the economic analysis of tire bale retaining wall, the B/C ratio was calculated to be 1.12 when the benefits to the whole society were considered. Based on the guidelines stipulated in Table 6.1, this will justify the construction of the project based on total costs and benefits for the society as a whole. As it was shown in Chapter 5, considering the interests of the City of Carlsbad alone, the project did not make economic sense because the cost of tire bale alternative was higher than the conventional alternatives. This highlights an important issue with regard to using large quantities of waste tires. For effective use of large volumes of scrap tires, waste tire disposal needs to be treated as a national or a state problem and the solutions to use (or dispose of) tires needs to be considered with social costs and benefits in mind.

This issue was highlighted at a national workshop organized in 1991 by the Center for Solid Waste Systems and Technology (CSWST). As a part of this workshop, approximately 80 individuals were invited to take part in a survey aimed at identifying the problems associated with the disposal and reuse of scrap tires and to recommend solutions. Twenty-four of the invitees participated in the workshop and this group comprised of twelve from the private industry, five from governmental agencies and seven from academic institutions. A list of 23 problems and issues were identified and each participant was asked to rank them. The top five rankings went to the following issues (JRMT 1991).

- Need for a tire recycling research institute
- Establish annual supply of tires from new discards and develop uniform procedures for tracking
- Convince the public that scrap tires, although classified as a waste, are a raw material
- Need for industry and government policies and infrastructure that encourage tire re-use
- Product research and development for innovative uses

All these issues point to the need for a concerted centralized effort towards solving the growing waste tire problem.

However, it needs to be emphasized that under the right economic conditions, an agency such as TxDOT may find that it is more economical to use waste tires instead of the more conventional alternative. This is illustrated by the results of the economic analysis as shown in Tables 6.2 and 6.3.

CHAPTER 7
CONSTRUCTABILITY REVIEW

7.1 INTRODUCTION

A brief discussion on constructability of projects using scrap tires is presented in this chapter. Constructability is a term of art which has come to encompass a detailed review of design drawings, specifications, and construction processes by a highly experienced construction engineer before a project is put out for bids. It is defined as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII, 1986). The purpose of the constructability review is to identify the following five items:

- Design errors, both material selection and dimensional
- Ambiguous specifications
- Project features that will be difficult or exceedingly costly to construct as designed
- Project features that exceed the capability of industry to properly build
- Project features that are difficult to interpret and will be hard to accurately bid

Under constructability review, a determination is made if the required level of tools, methods, techniques, and technology are available to permit an average construction contractor to build the project feature in question to the level of quality required by the contract. The constructability review also entails an evaluation of the ability of industry to understand the required level of quality and accurately estimate the cost of providing it. Thus, the level of risk due to misinterpretation that is inherent to a set of specifications or a project feature is reduced to the minimum level. When a formal constructability review is combined with a thorough economic analysis which springs from a current cost estimate, the final design as depicted by the plans and specifications is greatly enhanced, and the project is less susceptible to cost and time growth from change orders and claims. The benefits of a constructability review are:

- Reduced cost and shorter schedules
- Improved quality
- Enhanced safety
- Better control of risk
- Fewer change orders and claims

Application of constructability to transportation applications using whole tires was achieved by picking apart, piece-by-piece, the processes involved in each application. This process spanned from planning to construction completion looking for the following elements of the process that are inherently variable and difficult to replicate in the field.

- Quality of design
- Quality and consistency of construction
- Quality and consistency of materials
- Environmental conditions
- Loading (traffic) conditions, if applicable.

While the researchers will look at all these factors, the study will primarily focus on construction and materials. These two factors show the most promise for control through better training of field personnel. The objective of this exercise is to evaluate the final product in the context of complete process.

From a constructability standpoint, several factors stand out for the applications outlined in Chapter 5. One of the key constructability elements is the tire size. At this moment, TCEQ requires all scrap tire contractors to immediately shred tires and store them as tire chips. This is done to minimize tire fire hazard at tire stockpile locations. If tires are to be used as whole tire applications, arrangements need to be made to intercept tires before they are shredded. This would require stricter storage guidelines such that the tires are not exposed to elements during the storage and transportation. In all situations, the designer should ensure the availability of the adequate number of tires for the whole job in the sizes required. As a general rule, all tires and/or tire chips used in construction activity should be free of undesirable contaminants, including organic materials and fuel.

7.2 TIRES IN MARINE REEFS

The important elements in constructability and specifications for use of tires in marine reefs are outlined below.

- Size of tires – Uniformity of tire sizes is an important criterion for quality control.

- Construction location of marine reef units – These units are best constructed at the site where the units are to be deployed. This requires careful consideration of the tire transportation costs, which can be a significant component of the overall cost.

- Specifications for the reef involves provisions for tire sizes to be used, weight of reef unit and provision of adequate spacing for marine habitat to move around the reef unit. Under a method specification, the exact tire reef configuration such as the one displayed in Figure 5.3 can be specified with exact dimensions for the completed reef unit. For a performance-based specification, a minimum submerged density of 275 kg/m^3, submerged ballast to rubber ratio (by weight) of 10 and a ballast to tire ratio of 11 could be specified based on the New Jersey findings outlined in Chapter 5 (Myatt et al. 1988). This way, the contractor is free to come up with their own designs to meet the performance criteria. Under an end-result specification, a warranty period could be specified where the location of reef units could be checked to see if they remain in place.

7.3 TIRE BALES IN EMBANKMENT RETAINING WALLS

The important elements in constructability and specifications for use of tire bales in retaining wall construction are outlined below.

- Size of tires – Uniformity of tire sizes would be of paramount importance to ensure that the completed bales are stackable. If the bales are not stackable, it may significantly affect the construction process.

- Number of tires per bale – This will determine the stability provided by the bale, size of bale and its weight. Typically, each tire bale consists of 100 tires and weighs 1 ton. These parameters have a bearing on the baling equipment requirements, construction equipment requirements and the number of bales required for the design. Tire compressibility within the bale is important because fire hazard of the bales during the construction process (handling and storage) is minimized when the tires are packed tight.

- Specifications – In a method specification setting, the size, actual number of tires and the weight of bale could be specified. One drawback to this specification would be that depending on the type of tires used, the baler may or may not be able to achieve the required density and size. For performance based specifications, the weight and size of the tire bale could be specified without specifying the number of tire, which would depend on the compressibility of the tires.

7.4 TIRE CHIPS IN EMBANKMENTS

The important elements in constructability and specifications for use of tire chips in embankment construction are outlined below.

Size of tire chips – This will have a significant effect on the compactability of the embankment and eventually on its performance.

Maximum thickness of loose layer placed before compaction – Tire fills are extremely compressible and therefore, compacting them to the best achievable density is very important.

Need to seal tires from oxygen and organic materials – Anytime scrap tires are used in embankments, this becomes a critical issue

.

Specifications – In a method specification setting, information related to tire chip size, compaction requirements and top-soil thickness can be specified. Under performance-based specifications, allowable embankment deflections and allowable temperature rise in the tire fill needs to be specified such that the contractor is free to innovate with regard to tire chip size, encapsulation with geotextiles, etc.

7.5 ASPHALT-RUBBER SEAL COATS

The important elements in constructability and specifications for use of asphalt-rubber sea coats are outlined below:

- Gradation of crumb rubber – Influences the reaction and blending effectiveness

- Temperature at which crumb rubber and neat asphalt cement are blended – Affects binder aging.

- Application of asphalt-rubber binder – Effectiveness of binder application depends on this fact.

CHAPTER 8
DRAFT TXDOT SPECIFICATION FOR SCRAP TIRE USE

The following specifications are intended to promote the use of scrap tires in the form of tire bales and as tire chips in applications where their use has been proven. Tire bales may be used as embankment fill, retaining wall backfill, and in gabion baskets. Scrap tire bales have also been successfully used as a fill material in stream bank erosion control. The following specification generally addresses all the above-mentioned applications. The highlighted areas have been added to the existing specifications.

ITEM 132
EMBANKMENT

132.1 Description. This Item shall govern for the placement and compaction of all materials necessary for the construction of roadway embankments, levees and dykes or any designated section of the roadway where additional material is required.

132.2 Material. Materials may be furnished from required excavation in the areas shown in the plans or from off right of way sources obtained by the Contractor and meeting the requirements herein. All embankment shall conform to one of the following types as shown on the plans, except that material which is in a retaining-wall-backfill area shall meet the requirements for backfill material of the pertinent retaining-wall item:

Type A This material shall consist of suitable granular material, free from vegetation or other objectionable matter, and reasonably free from lumps of earth. This material shall be suitable for forming a stable embankment and, when tested in accordance with Test Methods Tex-104-E, Tex-105-E, Tex-106-E and Tex-107-E, Part II shall meet the following requirements:

The liquid limit shall not exceed	45
The plasticity index shall not exceed	15
The bar linear shrinkage shall not be less than	2

Type B This material shall consist of suitable earth material such as rock, loam, clay, or other such materials as approved by the Engineer that will form a stable embankment.

Type C This material shall be suitable and shall conform to the specification requirements shown on the plans.

Type D This material shall be that obtained from required excavation areas shown on the plans and will be used in embankment.

Type E This material shall consist of tire bales made of whole, used passenger vehicle tires or truck tires. Each bale shall contain only one type and size of tire, passenger or truck. The bales shall be produced in a tire baler or equivalent as approved by the Engineer. The tire baler shall be capable of compressing whole tires to reach a density not less than 35 lb/ft^3. Each bale shall use a minimum of 3 galvanized steel or stainless steel straps or wires. The bales shall not “explode” when all the straps are broken or cut.

The size and weight of each tire bale should be approved by the Engineer. To be eligible to supply tire bales to a project, the tire baler or the tire supplier shall be authorized to process waste tires by the Texas Natural Resource Conservation Commission.

The tire bales should be of uniform size within each project such that they can be easily stacked to facilitate rapid construction.

The tire bales should be load tested with the bale fully supported on a test floor approved by the Engineer. During load testing, the bale should be sandwiched between two steel plates. The top steel plate on which the load is applied shall be 1 inch thick and its size should be identical to the loaded area of the bale. I-section steel shall be used to distribute the load uniformly over the steel plate, as approved by the Engineer. The load shall be applied using a hydraulic ram with a load capacity of at least 400,000 lbs.

Two types of strength tests, a creep test and a compressive strength test, shall be conducted on tire bales. The creep test shall be conducted over 72 hours at a creep stress of 25 psi applied in the same direction along which loads are applied in the field. The maximum allowable creep strain shall not exceed 0.25. The compressive strength test shall be conducted until the tire bale fails or until an applied compressive stress of 100 psi, which ever is achieved first. In addition, the tire bales shall also have the following requirements:

The galvanized steel or stainless steel wires used as straps shall not break up to a stress of 50 psi as applied on the tire bale surface. With regard to corrosion of these straps, requirements stipulated in Item 423.2 shall be met. Tire bale fills covered with geomembranes, which makes the tire fill impermeable to air and water, may not be subjected to the pH and resistivity requirements stipulated in Item 423.2.

Type F. This material shall consist of either 100 percent scrap tire chips (also referred to as shreds) or a blend of scrap tire chips and conventional embankment fill material of Types A or B indicated above. The tire chips shall be obtained by shredding used passenger vehicle tires or truck tires. Based on the composition of the embankment material, embankment fills are divided into three classes:

> Class I fills are constructed using a blend of scrap tire chips and Type A or B material. Tire chips in Class I fills shall be free of contaminants such as oil, grease, gasoline, diesel fuel, etc. that could create a fire hazard. Under no circumstances shall remains of tires subjected to a fire be used as a part of fill.
>
> Class II fills are constructed either exclusively using tire chips or tire chips blended with less than 30 percent Type A or B material. The maximum allowable thickness of Class II tire chip fills is 3 feet. Tire chips in Class II fills shall be free of contaminants such as oil, grease, gasoline, diesel fuel, etc. that could create a fire hazard. Under no circumstances shall remains of tires subjected to a fire be used as a part of fill. For Class II fills, tire shreds shall have a maximum of 50 percent (by weight) passing the 1½ inch sieve and a maximum of five percent (by weight) passing the #4 sieve.
>
> Class III fills are constructed exclusively using tire chips with a tire chip fill thickness between 3 feet and 10 feet. No tire chip fill should be constructed exclusively with tire chips with tire chip layer thickness greater than 10 feet. Tire

chips in Class III fills shall be free of contaminants such as oil, grease, gasoline, diesel fuel, etc. that could create a fire hazard. Under no circumstances shall remains of tires subjected to a fire be used as a part of fill. For Class III fills, tire chips shall have a maximum of 25 percent (by weight) passing the 1½ inch sieve and a maximum of one percent (by weight) passing the #4 sieve. The tire chips shall be free from organic matter such as wood, wood chips and other fibrous organic matter. The tire chips shall have less than 1 percent (by weight) of metal fragments, which are not at least partially encased in rubber. Metal fragments that are encased partially in rubber shall protrude no more than 1 inch from the cut edge of the tire shred on 75 percent of the pieces and no more than 2 inches on 100 percent of the pieces.

Class III fills shall also be constructed such that infiltration of water and air is minimized. Also, there shall be no direct contact between tire chips and soil containing organic matter, such as topsoil. A minimum of 18 inches thick mineral soil layer free of organic matter shall be placed and compacted over the tire chip fill. This mineral soil fill shall be separated from the tire chip fill by a geotextile to prevent the soil particles from washing into the voids in tire chip fill. For Class II fills, use of drainage features located at the bottom of the fill that could provide free access to air should be avoided. These drainage features may include, but not limited to open graded drainage layers on the side of the fill, and drainage holes in walls.

132.3 Construction Method*s*.

(1) General. When off right of way sources are involved, the Contractor's attention is directed to Item 7, Legal Relations and Responsibilities to the Public.. Prior to placing any embankment, all work in accordance with Item 100, "Preparing Right of Way", shall have been completed on the areas over which the embankment is to be placed. Stump holes or other small excavations in the limits of the embankments shall be backfilled with suitable material and thoroughly tamped by approved methods before commencing embankment construction. The surface of the ground, including disk-loosened ground or any surface roughened by small washes or otherwise, shall be restored to approximately its original slope by blading or other methods. Where shown on the plans or required by the Engineer, the ground surface thus prepared shall be compacted by sprinkling and rolling.

The Engineer shall be notified sufficiently in advance of opening any material source to allow performance of any required testing.

Unless otherwise shown on the plans, the surfaces of unpaved areas (except rock) which are to receive embankment shall be loosened by scarifying to a depth of at least 6 inches. Hillsides shall be cut into steps before embankment materials are placed. Placement of embankment materials shall begin at the low side of hillsides and slopes. Materials which have been loosened shall be recompacted simultaneously with the new embankment materials placed upon it. The total depth of loosened and new materials shall not exceed the permissible depth of the layer to be compacted, as specified in Subarticle 132.3.(3).(a) and (b).

Trees, stumps, roots, vegetation or other unsuitable materials shall not be placed in embankment.

Unless otherwise shown on the plans, all embankment shall be constructed in layers approximately parallel to the finished grade of the roadbed.

Embankments shall be constructed to the grade and sections shown on the plans or as established by the Engineer. Each section of the embankment shall correspond to the detailed section or slopes established by the Engineer. After completion of the roadway, it shall be continuously maintained to its finished section and grade until the project is accepted.

(2) Constructing Embankments.

(a) Earth Embankments. Earth embankments shall be defined as those composed principally of material other than rock, and shall be constructed of acceptable material from approved sources.

Unless otherwise specified, earth embankments shall be constructed in successive layers for the full width of the individual roadway cross section and in such lengths as are best suited to the sprinkling and compacting methods utilized.

A minor quantity of rock or broken concrete encountered in the construction of this project may be incorporated in the lower layers of the embankment if acceptable to the Engineer. Or, it may be placed in the deeper fills, in accordance with the requirements for the construction of rock embankments, provided such placement of rock is not immediately adjacent to structures or in areas where bridge foundations are to be constructed. Also, rock or broken concrete may be placed in the portions of embankments outside the limits of the completed roadbed width where the size of the rock or broken concrete prohibits its incorporation in the normal embankment layers. All exposed reinforced steel shall be cut and removed from the broken concrete.

Layers of embankment may be formed by utilizing equipment and methods which will evenly distribute the material.

Each layer of embankment shall be uniform as to material, density and moisture content before beginning compaction. Where layers of unlike materials abut each other, each layer shall be featheredged for at least 100 feet, or the material shall be so mixed as to prevent abrupt changes in the soil. No material placed in the embankment by dumping in a pile or windrow shall be incorporated in a layer in that position, but all such piles or windrows shall be moved by blading or similar methods. Clods or lumps of material shall be broken and the embankment material mixed by blading, harrowing, disking or similar methods until a uniform material of uniform density is achieved in each layer.

Sprinkling required to achieve the moisture content necessary for compaction shall meet the material requirements of Item 204, "Sprinkling". It shall be the responsibility of the Contractor to secure a uniform moisture content throughout the layer by such methods as may be necessary. In order to facilitate uniform wetting of the embankment material, the Contractor may apply water at the material source if the sequence and methods used do not cause an undue waste of water. Such procedures shall be subject to the approval of the Engineer.

(b) Rock Embankments. Rock embankments shall be defined as those composed principally of rock, and shall be constructed of acceptable material.

Unless otherwise specified, rock embankments normally shall be constructed in successive layers for the full width of the individual roadway cross section and 18 inches or less in depth. When, in the opinion of the Engineer, the rock sizes necessitate a greater depth of layer, the layer depth may be increased as necessary, but in no case shall the depth of layer exceed 2-1/2 feet. Each layer shall be constructed in such a manner that the interstices between the larger stones are filled with smaller stones and spells which have been created by this operation as well as from the placement of succeeding layers of material.

The maximum dimension of any rock used in embankment shall be less than the depth of the embankment layer, and in no case shall any rock over two (2) feet in its greatest dimension be placed in the embankment unless otherwise approved by the Engineer. Unless otherwise shown on the plans, the upper or final layer of the embankment shall be composed of material so graded that the density and uniformity of the surface layer may be secured by the "Ordinary Compaction" or "Density Control" method. Exposed oversize material shall be reduced by sledging or other methods as approved by the Engineer.

When "Ordinary Compaction" is specified, each embankment layer shall be rolled and sprinkled when and to the extent directed by the Engineer. When "Density Control" is specified, each layer shall be compacted to the required density as outlined for "Earth Embankments", except that in those layers where rock will make density testing difficult, when shown on the plans, the Engineer may require the layer to be proof rolled to insure proper compaction.

(c) **Tire Bale Embankments.** Tire bale embankments shall be defined as those composed of scrap tire bales which are covered by a layer of soil. The maximum height of the tire bale portion of the embankment shall not exceed 10 feet. When tire-bale embankments are constructed, steps should be taken to eliminate free access to oxygen, water and organic materials to the locations where tire bales are stacked. These can be easily achieved by locating the tire bales away from open or underground drains and by eliminating the organic material coming into contact with the tire fill. A geomembrane that meets the Department specifications shall be used to wrap around the scrap tire fill to provide long-term durability to the embankment. Any soil that will come into contact with the tires shall be subjected to the color test for organic impurities in accordance with Test Method Tex-408-A with the test result not showing a color darker than standard.

When tire bales are being placed in horizontal layers, a spacing of at least 6 inches shall be left for placement of a soil filler material to be placed between the tire bales. A cohesionless material such as sand or manufactured stone sand shall be used for this purpose such that it is easily packed or vibrated between the bales. The same material or local material with a PI less than 35 shall be used to provide a cushioning layer between successive layers of tire bales. This layer should be at least 12 inches thick in order to facilitate compaction using vibratory rollers as specified in Item 217. Once compaction is completed on the last layer of tire bales, a geomembrane shall be used to completely cover the tire bale fill.

(d) **Tire Chip Embankments.** Tire chip embankments are constructed in 12-inch thick layers (in uncompacted form). For Class I fills, soil and tire chips shall be blended such that there is no likelihood of hrdrocarbon materials leaking from construction equipment onto the tire chips. They shall be mixed with equipment approved by the Engineer.

Any soil that will come into contact with the tires shall be subjected to the color test for organic impurities in accordance with Test Method Tex-408-A with the test result not showing a color darker than standard.

When Class II and Class III tire-chip embankments are constructed, steps should be taken to eliminate free access to oxygen, water and organic materials to the locations where tire chips are placed. This can be easily achieved by locating the tire chip fill away from open or underground drains and by eliminating the organic material coming into contact with the tire fill. A geomembrane that meets the Department specifications shall be used to wrap around the scrap tire fill to provide long-term durability to the embankment.

Rollers used for compaction of tire chip embankments shall meet the criteria in either Item 210, 211 or 212. Rollers with pneumatic tires shall not be used to compact tire chip fills.

(e) Embankment Adjacent to Culverts and Bridges. Embankments adjacent to culverts and bridges shall be compacted in the manner prescribed under Item 400, "Excavation and Backfill for Structures., or other appropriate bid items.

and six (6) inches in least dimension may be used. The percentage of fines shall be sufficient to fill all voids and insure a uniform and thoroughly compacted mass of proper As a general practice, embankment material placed adjacent to any portion of any structure and in the first two layers above the top of any culvert or similar structure shall be free of any appreciable amount of gravel or stone particles more than four (4) inches in greatest dimension and of such gradation as to permit thorough compaction. When, in the opinion of the Engineer, such material is not readily available, the use of rock or gravel mixed with earth will be permitted, in which case no particle larger than 12 inches in greatest dimension density. Tire bales may be used adjacent to culvert structures up to a height limit stipulated in Item 132.3 (2) c above. The bales shall be anchored to the culvert wall or into the underlying soil to a depth that will not allow stream erosion around or under the structure to wash away the tire bales under average storm water runoff conditions. This will be left to the discretion of the Engineer.

(3) Compaction Methods. Compaction of embankments shall be by "Ordinary Compaction" or "Density Control" as shown on the plans.

(a) Ordinary Compaction. When "Ordinary Compaction" is shown on the plans, the following provisions shall govern:

Each layer shall not exceed eight (8) inches of loose depth, unless otherwise directed by the Engineer. Each layer shall be compacted in accordance with the provisions governing the Item or Items of "Rolling". Unless otherwise specified on the plans, the rolling equipment shall be as approved by the Engineer. Compaction shall continue until there is no evidence of further compaction. Prior to and in conjunction with the rolling operation, each layer shall be brought to the moisture content directed by the Engineer, and shall be kept leveled with suitable equipment to insure uniform compaction over the entire layer.

Should the subgrade, for any reason or cause, lose the required stability or finish, it shall be recompacted and refinished at the Contractor's expense.

(b) Density Control. When "Density Control" is shown on the plans, the following provisions shall apply:

Each layer shall be compacted to the required density by any method, type and size of equipment which will give the required compaction. The depth of layers, prior to compaction, shall depend upon the type of sprinkling, mixing and compacting equipment used. However, maximum depth (16 inches loose and 12 inches compacted) shall not be exceeded unless approved by the Engineer. For tire chip fills, the maximum depth (loose) shall not exceed 12 inches. Prior to and in conjunction with the rolling operation, each layer shall be brought to the moisture content necessary to obtain the required density and shall be kept leveled with suitable equipment to insure uniform compaction over the entire layer.

Each layer shall be sprinkled as required and compacted to the extent necessary to provide the density specified below, unless otherwise shown on the plans.

Description	**Density, Percent**	**Moisture**
Non-swelling soils with plasticity index less than 20	Not less than 98	
Swelling soils with plasticity index of 20 to 35	Not less than 98 nor more than 102	Not less than optimum
Swelling soils with plasticity index over 35	Not less than 95 nor more than 100	Not less than optimum
Tire bale embankments	Not less than 98	

The density determination will be made in accordance with Test Method Tex-114-E. Field density determination will be made in accordance with Test Method Tex-115-E.

After each layer of earth embankment is complete, tests as necessary may be made by the Engineer. When the material fails to meet the density requirements or should the material lose the required stability, density, moisture or finish before the next course is placed or the project is accepted, the layer shall be reworked as necessary to obtain the specified compaction, and the compaction method shall be altered on subsequent work to obtain specified density. Such procedure shall be subject to the approval of the Engineer.

Excessive loss of moisture shall be construed to exist when the subgrade soil moisture content is four (4) percent less than the optimum.

The Contractor may be required to remove a small area of the layer in order to facilitate the taking of density tests. Replacement and compaction of the removed material in the small area shall be at the Contractor's expense.

When shown on the plans and when directed by the Engineer, the Contractor shall proof roll in accordance with Item 216, "Rolling (Proof)". Soft spots shall be corrected as directed by the Engineer.

132.4 Tolerances. The tolerances shall be as follows:

(1) Grade Tolerances.

(a) Stage Construction. Any deviation in excess of 0.1 foot in cross section and 0.1 foot in 16 feet measured longitudinally shall be corrected by loosening, adding or removing the material, reshaping and recompacting by sprinkling and rolling.

(b) Turnkey Construction. Any deviation in excess of 1/2 inch in cross section and 1/2 inch in 16 feet measured longitudinally shall be corrected by loosening, adding or removing the material, reshaping and recompacting by sprinkling and rolling.

(2) Gradation Tolerances. The Engineer may accept the material, providing not more than one (1) out of the most recent five (5) gradation tests performed are outside the specified limit on any individual sieve by more than five (5) %.

(3) Density Tolerances. The Engineer may accept the work providing not more than one (1) out of the most recent five (5) density tests performed is outside the specified density, provided the failing test is no more than three (3.0) pounds per cubic foot outside the specified density.

(4) Plasticity Tolerances. The Engineer may accept the material providing not more than one (1) out of the most recent five (5) plasticity index samples tested are outside the specified limit by no more than two (2) points.

132.5 Measurement. This Item will be measured as follows:

(1) General.
Retaining-wall-backfill areas which are also in embankment areas will be measured for payment as embankment except as shown on the plans; such material shall meet the requirements for backfill material of the pertinent retaining-wall item(s). Limits of measurement for embankment in retaining-wall areas will be as shown on Standard Detail Sheet "Earthwork Measurement at Retaining Walls" (EMRW) in the plans.

Shrinkage or swellage factors will not be considered in determining the calculated quantities.

(2) Class 1 Embankment will be measured in its original, natural position, and the volume computed in cubic yards by the method of average end area.

(3) Class 2 Embankment will be measured by the cubic yard in vehicles as delivered on the road.

(4) Class 3 Embankment will be measured by the cubic yard in its final position as the volume of embankment computed in place between (1) the original ground surfaces or the surface upon which the embankment is to be constructed, and (2) the lines, grades and slopes of the accepted embankment, using the average end area method.

(5) Class 4 Embankment will be measured by the each for the tire bales and by the cubic yard in vehicles as delivered on the road.

Class 3 is a plans quantity measurement Item and the quantity to be paid for will be that quantity shown in the proposal and on the "Estimate and Quantity" sheet of the contract plans, except as may be modified by Article 9. 8. If no adjustment of quantities is required, additional measurements or calculations will not be required.

132.6 Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Embankment", of the compaction method, type and class specified. This price shall be full compensation for furnishing embankment and tires; for hauling; for placing, compacting, finishing and reworking; and for all labor, royalty, tools, equipment and incidentals necessary to complete the work.

When proof rolling is shown on the plans and directed by the Engineer, it will be paid for in accordance with Item 216, "Rolling (Proof)".

When "Ordinary Compaction" is shown on the plans, all sprinkling and rolling, except proof rolling, will not be paid for directly, but will be considered subsidiary to this Item, unless otherwise shown on the plans.

When "Density Control" is shown on the plans, all sprinkling and rolling, except proof rolling, will not be paid for directly, but will be considered subsidiary to this Item.

When subgrade is constructed under this project, correction of soft spots in the subgrade will be at the Contractor's expense. When subgrade is not constructed under this project, correction of soft spots in the subgrade will be in accordance with Article 4.3.

CHAPTER 9
CONCLUSIONS

With nearly 2 billion tires lying in stockpiles and with many more being added each year, the scrap tire problem needs immediate attention. In the United States, one waste tire is generated per person per year, Therefore management of scrap tires is a challenging task. Approximately 75 % of the 250 million tires generated every year find established markets for their usage (25). These markets include energy recovery facilities, pyrolysis, manufacture of floor mats, and playground equipment. The remaining 25 % go into landfills, resulting in the occupation of already scarce storage space. Civil Engineering is a potential field where large quantities of raw materials are required. Therefore it is prudent to find ways to use large quantities of scrap tires in civil engineering applications.

This research included an evaluation of the scrap tire problem, its management in Texas, existing markets for scrap tires and civil engineering applications where scrap tires can be used in large quantities. Tire rubber in pavements is by and large, the only existing civil engineering application that is worth mentioning. Three other applications were highlighted in Chapter 5 that deserve serious consideration for large-scale use of scrap tires in transportation engineering applications. These applications are whole tires in marine reef construction, tire bales in retaining wall construction, using tire chips in embankment construction, and asphalt-rubber in pavement applications.

From an economic standpoint, it is relatively easy to justify the use of scrap tires in most Texas localities for the applications outlined above because of the immense benefits it provides to the society as a whole. However, for agencies such as TxDOT, it may be harder to justify the use of scrap tires for construction applications due to the relative inexpensiveness of conventional materials. As shown by the results of cost-benefit analysis (Tables 6.2 and 6.3), economic justification may be possible for TxDOT under specific local conditions. The State of Arkansas Department of Environmental Quality, in its policy on use of baled tires, indicated that the suitability of tire bales for construction applications is best judged by the local entities because of the variation of economic factors from one region to another.

The draft specification developed in this research for scrap tire use in TxDOT was aimed specifically for the embankment applications because of the proven technical and environmental feasibility for that application.

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APPENDICES

APPENDIX A
ADDITIONAL SCRAP TIRE APPLICATIONS

A.1 FENDERS

Schuyler Rubber Company uses laminated rubber recycled from post consumer-bias ply trucks for the manufacture of marine rubber fenders. Laminated rubber is used over virgin extruded and molded rubber for tugs, pushboats, barges, ferries, piers, docks, dolphins, trawlers and other marine vessels and structures. Laminated rubber fenders are custom built to fit complex conical shapes, sharp radius corners, deck falls, stem rakes, and tapers. Each section is delivered complete with hangers and weld tabs ready for installation. Virgin rubber products, on the other hand, must be modified at additional cost before a fender is created. Even then, virgin rubber cannot be effectively fitted to many odd-shaped areas as laminated rubber can. Laminated rubber fenders contain tough plies of nylon and cloth internal reinforcement unlike virgin rubber. As a result, chipping, cracking and cutting often associated with virgin rubber is virtually eliminated. The load deflection, energy absorption, and chemical properties of laminated rubber equal or exceed those of virgin rubber. Schuyler Rubber Company claims that its SR3D Fender is the softest and most energy absorbent fender system offered today. In addition, laminated rubber is available in a broader range of softness (i.e. energy absorption) as compared to other fendering materials.

A.2 EROSION CONTROL

The California Office of Transportation Research has designed and tested several erosion control applications of scrap tires. They found that tires used with other stabilization materials to reinforce an unstable highway shoulder to protect a channel slope remained stable and can provide economical and immediate solutions. Construction costs were reduced from 50 to 75 percent of the lowest cost alternatives such as rock, gabions or concrete protection.

A.3 HIGHWAY CRASH BARRIERS

In the late 1980's, Texas Transportation Institute studies the use of scrap tires in crash barriers. They determined that stacked tires bound by a steel cable and enclosed with fiber glass would reduce or absorb impact of auto mobiles traveling up to 71 miles per hour. However, State Transportation Department prefer sand-filled crash barriers because they have excellent absorption characteristics and are easier to erect and dismantle.

A.4 TIRE DERIVED FUEL (TDF)

The use of scrap tires as a supplemental fuel in cement kilns continues to be a dynamic market because of their high operating temperatures(2600 F)and good conditions for complete combustion. Also, there is no residue, since the ash is incorporated into the cement product
Kilns currently using scrap tires have been individually permitted volume capacities ranging from 250,000 to 3 million scrap tires per year. According to STMC, the driving forces behind TDF have been improved emissions, increased production and decreased fuel cost.

<u>Volume Characteristics</u>
The following is an estimate of the potential usage of scrap tires by the US cement industry:

Current usage	45.5 million scrap tires per year
Current permitted capacity	47 million scrap tires per year
Within 2 years	58 million scrap tires per year
Within 5 years	70 million scarp tires per year.

Scrap Tire Fuel in Lime Kilns

The use of scrap tires as a supplemental fuel in lime kilns is a new market niche for TDF.

Lime kilns ,like their cousins, cement kilns , are an energy intensive process. The level of heating value in TDF is clearly of interest to this industry. The differences between lime kilns and cement kilns is that the lime kiln is shorter in length and often produces a different color and product. Some commercial lime must be white, while cement is usually gray. The use of TDF in lime kilns, under certain circumstances, can darken the product. If the color of lime is a critical element for its sale, the use of TDF will not be possible.

APPENDIX B
AGENCIES OR PERSONS CONTACTED

Person	**Agency**	**Contact**
Ron Reese	California DOT	(916)227-7108
Rod Prysocks	California DOT	(916)227-7171
Walter Hoey.Jr	Delaware DOT	(302)739-4852
Bob Smith	Idaho DOT	
Jim Trepanier	Illinois DOT	(217)782-7200
Joe Gunderson	Indiana DOT	(317)232-5280
Glenn Roberts	New Hampshire DOT	(603)271-1660
Carol Nash	New Jersey Environment and Fisheries Dept.	(609)292-2965
Philip L. Western	New Mexico Environment Department	(505) 827-0559
Steve Murphy	North Carolina Division of Marine Fisheries	(919)726-7021
Page Buechley	TCEQ	(512_239-6704
Nick Classen	TCEQ	(512)239-6790
David E. B. Nightingale	Washington State Department of Ecology	(360) 407-6392
Jim Coffins	Wisconsin DOT	(307)777-4418
Vernie	Encore Balers	
	Texas Natural Resources Conservation Commission (TCEQ) web page	www.TCEQ.state.tx.us/enforcement/tires
	Encore Balers web page	www.northernnet.com/baler
	Dunlop tires web page	www.dunlop.tire.com
	Goodyear tires web page	www.goodyear.com
	Coopre tires web page	http://coopertires.com
	EnviroSense home page	http://es.inel.gov/techinfo/facts
	North Carolina Division of Marine Fisheries	www.sips.state.nc.us/EHNR/DMF/reefs
	Schuyler Rubber Company	www.schuylerrubber.com

APPENDIX C
SCRAP TIRE OUTREACH ACTIVITIES

C.1 PUBLICATIONS

1. Scrap Tire Management Council (STMC) outreach activities including publications
2. Scrap Tire News magazine