

**Report No. CDOT-DTD-R-2005-2
Final Report**

TIRE BALES IN HIGHWAY APPLICATIONS: FEASIBILITY AND PROPERTIES EVALUATION

Jorge G. Zornberg, Ph.D., P.E.

Barry R. Christopher, Ph.D., P.E.

Marvin D. Oosterbaan, P.E.



March 2005

**COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH**

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. Report No. CDOT-DTD-R-2005-2	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle TIRE BALES IN HIGHWAY APPLICATIONS: FEASIBILITY AND PROPERTIES EVALUATION		5. Report Date March 2005	
7. Author(s) Jorge G. Zornberg, Barry R. Christopher, and Marvin D. Oosterbaan		6. Performing Organization Code	
9. Performing Organization Name and Address Jorge G. Zornberg, PhD, P.E., Department of Civil Engineering, The University of Texas at Austin, TX Barry R. Christopher, PhD, PE, 210 Boxelder Lane, Roswell, GA Oosterbaan Consulting LLC, 1112 Washington Street, Cape May, NJ		8. Performing Organization Report No. CDOT-DTD-R-2005-2	
12. Sponsoring Agency Name and Address Colorado Department of Transportation – Research Branch 4201 E. Arkansas Ave. Denver, CO 80222		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 80.14	
15. Supplementary Notes Prepared in cooperation with the US Department of Transportation, Federal Highway Administration		13. Type of Report and Period Covered	
16. Abstract There are growing interests in the utilization of recycled tire bales for civil engineering applications, triggered partly by the significant volumes of tires that could be disposed of in transportation projects. However, evaluation of tire bale properties and performance of tire bale embankments is, at least, limited. This report summarizes the benefits and shortcomings of using tire bales in civil engineering projects, as well as information collected to date on their mechanical properties. The report includes the results of eight laboratory tests on typical tire bales (most of which had never been performed prior to this study) to provide critical information on tire bale geometry, both air dry and submerged unit weights, permeability, unconfined and confined compressibility characteristics including horizontal deformations, rebound and potential expansion pressures, creep behavior, and external shear strength between two tire bales. An economic analysis comparing the estimated cost of tire bales to conventional fills is presented, supported by information on Colorado DOT costs for earth embankments. Finally, detailed recommendations for utilization and implementation of tire bales as a lightweight fill in embankments are presented. Implementation: Following a review of the final report by CDOT and FHWA experts, a special provision for tire bale embankments should be developed as part of CDOT Section 203 "Embankments." The CDOT regional offices should be informed of the new specification and the potential cost savings for using tire bales in generic embankment applications. Prototype sections where tire bale embankments can be used should be identified on noncritical projects (e.g., embankments on secondary, non-lifeline roads). All embankments constructed with tire bales should be monitored, and annual performance reports will be prepared during a recommended five-year observation period. The study has also demonstrated that tire bales: 1) should be considered a viable cost-effective alternative when and where lightweight fills are required on CDOT projects, and 2) have a potential for other applications, including slope repairs, rockfall barriers, insulation of frost-susceptible soils, drainage zones, and erosion protection.		14. Sponsoring Agency Code	
17. Keywords scrap tires, transportation embankments, laboratory tests, fire protection, prototype test sections		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, 5825 Port Royal Road, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 204	22. Price

TIRE BALES IN HIGHWAY APPLICATIONS: FEASIBILITY AND PROPERTIES EVALUATION

by

Jorge G. Zornberg, Ph.D., P.E.

Barry R. Christopher, Ph.D., P.E.

Marvin D. Oosterbaan, P.E.

Report No. CDOT-DTD-R-2005-2

Sponsored by the
Colorado Department of Transportation
In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9506

Acknowledgements

The research in this report was conducted under Colorado Department of Transportation Research Branch Project CDOT-DTD-R-2005-2, titled “Tire Bales in Highway Applications: Feasibility and Properties Evaluation.” We appreciate the Department’s support of this project.

The Colorado Department of Transportation Study Panel consisted of Dr. Naser Abu-Hejleh (Research), Mr. Rob Beck, Geotechnical Program (Materials), Mr. Rich Griffin (Research), and Mr. C. K. Su (Materials).

The research was conducted from January 2003 to November 2004. The principal investigators for the project were: Dr. Jorge Zornberg, Clyde E. Lee Assistant Professor, Department of Civil Engineering, The University of Texas at Austin; Dr. Barry R. Christopher, Ph. D., P.E., Geotechnical Consultant, Roswell, GA.; and, Mr. Marvin D. Oosterbaan, P.E. Oosterbaan Consulting LLC, Cape May, NJ. Also working on this project were Mr. Christopher J. LaRocque, Graduate Student at The University of Texas at Austin, Department of Civil Engineering, Austin, TX, and Mr. Timothy Fitzgerald, Graduate Student, University of Colorado at Boulder, Colorado.

We are especially grateful for the cost data Mr. C. K. Su, Colorado DOT, Denver Co. provided; the information on the history of tire baler development and tire bale applications Ms. Nancy Drews, Encore Systems, Cohasset, MN made available; the draft tire bale specification Mr. Richard Williammee, Texas Department of Transportation, provided; and, the comments Mr. Kenneth P. Smith, Deputy Director – Transportation, Chautauqua County, NY made on the recent applications of tire bales for their projects. Mr. Rick Welle of Front Range Tire Recycle Inc. provided information on the case history in Sedalia, Co, and provided the tire bales tested in this study. Special thanks is also extended to Mr. Jianren Wang and his staff at Geotesting Express and to Professor Lawrence Kahn and the students who assisted him at the Georgia Institute of Technology for their diligence and special effort in completing the laboratory testing on the tire bales.

Executive Summary

Recent estimates indicate that more than 2 billion scrap tires are currently stockpiled in the United States and approximately 280 million more tires are added annually. State regulations now guide the stockpiling of scrap tires and their reuse for beneficial purposes. Approximately 77 percent of the tires discarded each year are processed and recycled for various uses. Since 1985, scrap tires have been used in a variety of civil engineering applications, including tire shreds to provide economical lightweight embankments for transportation projects. This application can use 100,000 to 1,000,000 tires per project. Another approach that has slowly developed in the past 15 years is mechanically compressing and tying 100 whole tires to form large "bales" which are stacked to form part of an embankment.

This research was performed to evaluate the technical and economic feasibility of using tire bales in embankment construction and determine relevant engineering properties for design. The research work was conducted in two phases. The objective of Phase I was to review, document, and synthesize approximately 14 years of experience, primarily in the USA, UK, and Australia, using tire bales in civil engineering applications. The Phase II objectives were to evaluate the technical and economic feasibility of tire bales as an embankment material; compare tire bales with other lightweight fill materials; perform laboratory tests to determine some of the basic engineering properties of typical tire bales; review design guidelines; and identify construction issues, quality control requirements, estimated costs, and limitations associated with the use of tire bales. Prior to this study the only available laboratory tests of tire bales consisted of two tests of unconfined compression and short-term creep conducted in 2000. Therefore a significant part of the Phase II work included performing a series of laboratory tests to evaluate engineering properties of tire bales relative to embankment applications, which provide essential data for the feasibility evaluation. A series of eight laboratory tests on eight typical tire bales were performed under a Colorado Department of Transportation contract with GeoTesting Express in 2004 - 2005. Most of the eight tests had never been performed or at least reported in the available literature, prior to this study. The results of the 2004 - 2005 tests are presented in Appendix D and included in the tables of typical tire bale properties along with the 1999 laboratory test data, which is reported in Appendix C.

The results of the Phase II work confirmed the initial expectation that tire bales are a feasible structural material for various embankment applications. This report combines the Phase I and Phase II work and is the product of the three principal investigators.

The research study to date confirms that tire bales can be an economical material that provides a lightweight, strong, porous embankment, easily and rapidly constructed in a number of civil engineering applications. This use of scrap tires also provides a significant opportunity to enhance the environment, continue the cleanup of unregulated tire dumps, reduce the possibility of expensive tire fires, and remove potential breeding grounds for mosquitoes. This use of tire bales provides additional opportunities for the scrap tire recycling industry because it utilizes simple machinery that can be operated by relatively unskilled workers to fabricate a product that can be stored in strategically located stockpiles (in a protected facility) until it can be trucked to and utilized at a construction site.

However, additional information should be obtained by monitoring in-service performance of prototype tire bale embankments. Instrumentation must be installed in the prototype tire bale embankment sections to monitor internal temperatures, assess the heat buildup, and further evaluate the potential and possibility of significant exothermic reactions. Compression settlement must also be monitored to compare the results of laboratory tests on tire bales with in-service performance.

The observations will be used to enhance the development of design procedures, construction specifications, and other requirements for Class I and Class II tire bale embankments. The detailed recommendations for the next steps are included in Section 10 of this report.

Cost estimates for a basic tire bale embankment are presented in Tables 7.1 to 7.3. The analysis indicates that the net cost of a tire bale core zone, replacing embankment fill material in a typical highway embankment, is in the order of \$3.70 to \$9.70 /m³ (\$2.80 to \$7.40 cy) (assuming the current Colorado rebate for using scrap tires is in force). This use of tire bales indicates a potential cost savings when compared to the average annual cost of embankment material backfill of \$12.60/m³ (\$5.00/cy) for 125 CDOT projects in the 2001 to 2003 time period. The

125 projects constitute 50 percent of the CDOT embankment projects, all having embankment volumes in the range of 3,300 to 38,200 m³ (2,500 to 50,000 cy), during the 2001 to 2003 time period. This estimate does not include costs for cleaning scrap tires, connection materials, earth matrix infilling, drainage materials, or engineering services that usually vary with any project and the site constraints.

Implementation Statement

Following a review of the final report by CDOT and FHWA experts, a special provision for tire bale embankments should be developed as part of CDOT Section 203 “Embankments.” The CDOT regional offices should be informed of the new specification and the potential cost savings for using tire bales in generic embankment applications. Prototype sections where tire bale embankments can be used should be identified on noncritical projects (e.g., embankments on secondary, non-lifeline roads). All embankments constructed with tire bales should be monitored, and annual performance reports will be prepared during a recommended five-year observation period.

In addition to use of tire bale zones in generic embankments, tire bales have a high potential for a number of special applications, including slope repairs, rockfall barriers, insulation of frost-susceptible soils, drainage zones, and erosion protection. The study has also demonstrated that tire bales should be considered a viable cost-effective alternative when and where lightweight fills are required on CDOT projects. Implementing the use of tire bales for these special applications will require use and assimilation of the additional information obtained by monitoring in-service performance of prototype tire bale embankments as described above. In some cases additional instrumentation should be installed in the prototype tire bale embankment sections to obtain particular data. The observations of the test embankments will be used to enhance the development of design procedures, construction specifications, and other requirements for Class I and Class II tire bale embankments and special applications. The detailed recommendations for the next steps are included in Section 10 of this report.

The benefits derived from this research will accrue to the state of Colorado, as well as the national and international community. The primary benefits include lower cost for transportation embankments, development of another use of a significant waste material, by use of “low-tech” fabrication equipment, low-cost labor, conventional transport, a low-end handling system, and conventional support materials.

TABLE OF CONTENTS

1	INTRODUCTION.....	1
2	CURRENT REUSE OF WASTE TIRE PRODUCTS.....	6
2.1	Whole tires.....	6
2.2	Tire pieces and tire shreds	7
2.3	Soil and tire shred mixtures	9
2.4	Tire bales.....	10
2.4.1	Selected case histories.....	12
2.4.2	Other transportation applications	14
2.4.3	Need for additional research	14
3	CHARACTERISTICS OF WASTE TIRES, TIRE SHREDS AND TIRE BALES	16
3.1	General characteristics of rubber tires	16
3.2	Characteristics of tire shreds	17
3.3	Characteristics of tire bales.....	19
3.3.1	Tire bale fabrication.....	19
3.3.2	Tire bales as engineered lightweight fill.....	21
3.3.3	Tire bale properties.	21
3.4	Evaluation of potential exothermic reactions in tire bales.....	23
3.4.1	Regulatory guidance for storing scrap tires	26
3.4.2	Reports of tire bale storage requirements and fires.	28
3.4.3	Summary of fire protection evaluation	29
4	MEASURED PHYSICAL AND MECHANICAL PROPERTIES OF TIRE BALES FROM LABORATORY TESTS	31
4.1	Geometry of the exterior surfaces of the tire bale	32
4.2	Dry, wet and submerged unit weight of “as received” tire bales.....	32
4.3	Vertical permeabilty of tire bales	33
4.4	Compressibility tests with both vertical and horizontal deformation measurements.....	34
4.5	Unconfined and confined compressibility tests (i.e., without and with infill materials) at working loads, including static and cyclic modulus evaluation.....	36
4.6	Time-dependent deformation of tire bales under sustained load (i.e., creep).....	38
4.7	Shear strength of interface between two vertically stacked tire bales	41
4.8	Rebound of tire bales and potential expansive pressure of tire bales	42
4.9	Summary of measured tire bale properties	43
4.10	Material properties of tire bales and other lightweight fills.....	47
5	TIRE BALES IN TRANSPORTATION APPLICATIONS	52
5.1	Introduction.....	52
5.2	General embankment construction	53
5.3	General slope repair and stability improvement system.....	55
5.4	General rockfall barrier walls	57

6	DESIGN GUIDELINES FOR TIRE BALE EMBANKMENTS.....	60
6.1	General.....	60
6.2	Lightweight fill systems	60
6.3	Tire bale specifications	61
6.3.1	Summary of Texas DOT preliminary draft specification	63
6.3.2	Comments on the Texas preliminary draft tire bale specification	64
6.4	Tire bale fabrication	67
6.5	Construction sequence.....	68
6.5.1	Pre-construction	68
6.5.2	Field operations.....	68
6.5.3	Monitoring field activities.....	71
7	ESTIMATED COSTS FOR TIRE BALE EMBANKMENTS	72
7.1	Colorado rebates and reported cost savings.....	72
7.2	Estimated cost of a tire bale embankment in Colorado	73
7.3	Comparison of estimated cost for lightweight fill	77
7.4	Discussion of other cost issues for tire bale embankments.....	77
8	FEASIBILITY, FEATURES, BENEFITS, AND DESIGN/ PERFORMANCE ISSUES.....	79
8.1	Feasibility.....	79
8.2	Features and benefits.....	79
8.3	Special considerations, limitations, and research issues.....	80
8.4	Design/performance issues.....	85
9	VIABILITY AND FUTURE EFFORTS.....	87
9.1	Recommended field testing	88
10	CONCLUSIONS AND RECOMMENDATIONS.....	92
10.1	Conclusions.....	92
10.2	Recommendations	94
	REFERENCES.....	98
	APPENDIX A Tire Bale Applications for Civil Engineering Projects.....	A-1
	APPENDIX B Case Studies of Tire Bale Applications for Transportation Projects.....	B-1
	APPENDIX C General Properties of Tires and Results of March 2000 Tire Bale Lab Tests.....	C-1
	APPENDIX D 2004 Lab Test Data on Tire Bales (performed for this study).....	D-1
	APPENDIX E Specifications for Tire Sheds and Tire Bale Applications.....	E-1
	APPENDIX F References for Governmental Legislation and Scrap Tire Reuse Programs.....	F-1
	APPENDIX G Fire Protection Issues and Guidelines for Scrap Tires.....	G-1
	APPENDIX H Colorado DOT Costs for Embankment Materials and Related Items.....	H-1

LIST OF TABLES

Table 2.1	Reported and possible uses of tire shreds, whole tires, and tire bales.	11
Table 3.1	Typical physical characteristics of tire bales	20
Table 3.2	Preliminary application of tire shred guidelines to tire bale embankments.....	24
Table 4.1	Physical and mechanical properties of tire bales.	44
Table 4.2	Summary of various lightweight fill materials (from Stark, et al., 2002).....	48
Table 4.3	Comparison of typical reported properties of tire bales, tire shreds, EPS blocks, and earth fill materials	49
Table 6.1	Authors' summary of design issues for tire bale embankments, slope repairs and rockfall barrier applications.	62
Table 7.1	Estimated base cost of tire bale embankments in Colorado.	70
Table 7.2	Estimated cost of tire bales for embankment construction	71
Table 7.3	Estimated cost of special material and site requiremnts.	72
Table 8.1	Issues related to use of tire bales as embankment fill.....	85
Table 9.1	Instrumentation program to monitor tire bale issues for embankment fill applications.	89

LIST OF FIGURES

Figure 2.1	Geosynthetic reinforced soil (GRS) rockfall barrier with tire facing in New Mexico (Christopher, 2002).....	7
Figure 3.1	Typical tire bale.....	19
Figure 4.1	Typical tire bale compression test setup.....	35
Figure 4.2	Stress-strain results from tire bale compression tests.....	35
Figure 4.3	Confined and unconfined cyclic load test results.....	37
Figure 4.4	Unconfined and confined stress-strain characteristics of tire bales.....	37
Figure 4.5	Creep test setup.....	39
Figure 4.6	Creep test results showing: a) 15 kPa (314 psf) normal stress test, b) 39 kPa (815 psf) normal stress test, and c) repeat 39 kPa (815 psf) normal stress test.....	40
Figure 4.7	Shear between two vertically stacked tire bales.....	41
Figure 4.8	Rebound test on tire bales showing lateral expansion in the first test.....	43
Figure 5.1	Application of tire bales in embankment construcion.....	55
Figure 5.2	Tire bales used to improve slope stability.....	52
Figure 5.3	Stacked tire bales, e.g., to form the impact face of a rockfall barrier (Encore Systems Inc, 2004).....	55
Figure 7.1	Total taxpayer disposal costs for each tire	72
Figure 7.2	Total savings per 1000 feet of roadbed	73

1 INTRODUCTION

Recent estimates indicate that more than two billion waste passenger car and truck tires are currently stockpiled across the nation (Senadheera, 2002). In addition to the existing stockpiles, scrap tires are being generated in the United States at an approximate rate of one per capita annually, totaling 280 million scrap tires (RMA, 2002 and Bosscher et al., 1997).

Tires are made of vulcanized rubber, allowing them to retain their elasticity. By definition, thermosetting polymers cannot be returned to their original form. Because of this, waste tires cannot be “recycled” but must be reused or discarded. An estimated 77.6% of the total generated tires in 2001 were used for various applications (RMA, 2002). The remaining unused tires are stockpiled or illegally dumped in loose random piles of whole tires. Large stockpiles of whole and processed waste tires can present environmental problems and dangers, such as the breeding of mosquitoes and rodents, and become serious fire hazards (Humphrey and Manion, 1992). Another significant means of disposing waste tires is incineration for tire-derived fuel (TDF). This accounts for approximately 17% of the waste tires produced (Bosscher et al., 1997). While this means of reuse may be a significant source of energy, it results in increased atmospheric pollution.

Alternative means of disposing waste tires have been introduced in the last decade including the reuse of waste tire products in civil engineering applications. Scrap tire materials are characterized by their lightweight, low lateral pressure, low thermal conductivity and good drainage characteristics. Due to tipping fees required by many state laws for tire disposal, tire bales are very economical. The economics and engineering properties make waste tire products desirable for use in many applications, including the construction of nonstructural sound barrier fills, lightweight embankment fills crossing soft or unstable ground, pavement frost barriers, retaining-wall backfills, and edge drains (Bosscher et al., 1997 and Baker et al., 2003). Additional applications are rockfall barriers, field drains, and blasting mats. The vibratory damping property of waste tire products makes them a possible candidate in seismic stability applications.

If implemented on a large scale, the utilization of tire shreds in civil engineering projects could represent a significant means of disposal for scrap tires. Depending on the size of the projects, anywhere from 100,000 to upwards of 1 million waste tires may be used on a single project (Humphrey, 1996). The use of waste tires, either whole or processed, in civil engineering projects tends to reduce the environmental problems associated with alternative means of disposal, and also reduces the use of other non-renewable mineral aggregates. In some cases, it has been determined that mixing tire shreds with soil increases the shear strength of the soils (Zornberg, et al., 2004a). Various studies suggest that waste tire products used in these applications do not pose a significant threat as a hazardous waste material, and do not alter the concentrations of any substances affecting the primary drinking water standards set forth by EPA (Edil and Bosscher, 1992 and Humphrey et al., 1997) (Edil and Bosscher, 1992 and Humphrey et al., 1997). In some cases, oxidation of exposed steel in shredded tire fill caused increased levels of manganese (Mn) and iron (Fe), often exceeding their secondary (aesthetic based) standard (Humphrey, et al., 2001).

The most common form of processed waste tires has been the use of tire shreds as monofill zones within a soil matrix, or as a tire shred/soil mixture. Through 1995, more than 70 civil engineering projects had been successfully completed in which tire shreds, the prominent reusable waste tire product applicable to the civil engineering industry, were used in various forms and did not experience an exothermic reaction (Humphrey, 1998). This document includes a table which lists 18 projects in 10 states during the 1989 to 1994 time period where significant construction information is available. Baker et al. (2003) cites 32 projects in 13 states where tire shreds were used in geotechnical applications. Apparently, well over a hundred projects involving the reuse of tire shreds have been constructed in the past 20 years.

Several cases have been documented in which whole tire and tire shred stockpiles and tire shred embankments have experienced internal heating, resulting in severely damaging, costly fires (Humphrey, 1996 and Baker et al., 2003). Humphrey 1998 and ASTM D6270-98 include guidelines to reduce the risks associated with development of an exothermic reaction in stockpiles of whole tires and tire shred embankments more than 1 meter (3.3 ft) thick. One recommendation states that tire shreds with larger dimensions will minimize exposure of the exposed steel, the corrosion of which is thought to be the major source of internal heating.

Presence of organic material and exposure to air, water, increase the potential for corrosion and are therefore restricted in the guidelines. Limitations on fill height are also imposed. Although some research into the sources of internal heating of tires and tire shreds has been conducted, a complete understanding of the causes of exothermic reactions in tire shred fills is still lacking.

A Special Report titled “Scrap and Shredded Tire Fires” (United States Fire Administration, 1998), based on a detailed analysis of seven tire fires in the 1995 to 1997 time period, describes 12 key issues associated with reducing the possibility and impacts of tire fires in various settings. The key issues include code enforcement, agency coordination, equipment needs, extinguishing tactics and agents, disposal of burned tires, and costs. A detailed discussion of the 12 key issues is beyond the scope of this study, however, they must be considered in the in-service use of waste tire products for civil engineering applications as described in later sections of this report.

The focus of this study and the report is the practical use of whole tires compressed into bales and placed as part of an earth embankment. This is a relatively new approach, which appears to provide a viable alternative to the use of tire sheds in civil engineering applications and reduces the potential for exothermic reactions. Tire bales also appear to provide some economic advantage over the use of tire shreds in terms of production, storage, and construction costs as reviewed later in this report. However, when this study was initiated, comparatively little testing and/or research have been completed regarding the engineering properties and performance of tire bales used in civil engineering applications.

As the reuse of various waste tire products in civil engineering applications increases, the need for better understanding of the engineering properties of whole and processed waste tires becomes paramount. It has been noted that reuse of waste tires has the potential of becoming the most reusable secondary material in the world, possibly reaching 75% of all scrap tires generated in the near future (Enviro-Block). While research is needed to provide guidelines on appropriate design methods and construction practices for using baled tires in transportation systems, significant lessons can be learned from a review of projects already constructed using baled tires.

The overall objectives of this study are to:

1. Evaluate the feasibility of using baled tires as embankment materials in highway applications.
2. Evaluate the engineering characteristics of tire bales through a review of the literature and the performance of laboratory tests.
3. Provide recommendations for construction of tire bale embankments, in conjunction with appropriate soil, rock, connecting systems, and geosynthetic materials based on the lessons learned from limited experience with using tire bales as embankment materials, and the comparison of tire bale properties with similar applications using other lightweight materials, e.g. tire shred fills, expanded polystyrene (EPS), and the authors' opinions and judgment.
4. Provide preliminary recommendations for the use of tire bale embankments in slope repairs and rockfall barriers.
5. Provide a summary of the issues that need further research to demonstrate the suitability of tire bales in transportation systems, including the engineering properties of tire bales related to design, construction, and long-term performance.
6. Provide a research plan with detailed tasks and an estimated budget for the construction, instrumentation, and monitoring of a prototype tire bale embankment constructed to address the issues described in Objective 4 above.

This report summarizes:

- Reported and possible uses of scrap tires in Section 2.
- The current design guidelines for tire shred fills (ASTM D6270-98) in Section 2.
- Typical characteristics of whole tires, tire shreds, and tire bales in Section 3.
- Measured physical and mechanical properties of tire bales in Section 4.
- Typical properties of tire bales, tire shreds, EPS blocks, and conventional earth fills in Section 4.
- The status of knowledge and understanding, as well as a relative assessment of the design issues relating to use of tire bales in embankments, slope repairs, and rockfall barrier applications in Section 5.
- Tire bale specifications in Section 6.
- Construction issues in Section 6.

- Estimated costs for tire bale embankments in Section 7.
- Special considerations, limitations and performance issues in Section 8.
- Available information on performance of tire bale embankments.
- An outline of future laboratory and field research activities in Section 9, including appropriate field instrumentation.

Several Appendices are included which contain selected case studies of reported tire bale applications (Appendix A and B), results of available laboratory tire bale tests (Appendix C and Appendix D), typical specifications (Appendix E), references to governmental legislation relating to use of scrap tires (Appendix F), reference to fire protection issues and guidelines for scrap tires (Appendix G) and recent Colorado DOT costs for embankment materials and related items (Appendix H).

2 CURRENT REUSE OF WASTE TIRE PRODUCTS

While waste tire products are currently being used in various civil engineering applications, the search continues for products and applications that maximize the performance capabilities, pose limited risks, and are comparatively economical. The typical forms of waste tires include: powdered, ground and granulated rubber, tire shreds, split tires, whole tires, and tire bales.

2.1 Whole tires

Whole tires have been used in applications ranging from residential construction to reinforced soil slopes. In residential construction, whole tires have been used as the primary material for constructing both exterior and interior walls before the tires are covered with a surface finish layer of cement material. The use of tire bales in these projects is beneficial both in terms of the use of waste tires, as well as the energy efficiency of the completed walls. Whole tires are generally laid on concrete footers and subsequently filled with compacted soil. Walls are built by using several layers of whole tires filled with soil and stacked on one another. These “tire walls” are typically ‘finished’ by applying a layer of shotcrete, stucco, or some other finish material. The result is a house built with relatively inexpensive materials and the exterior walls have extremely high thermal resistance values. (Touch the Earth Construction, 2004).

Whole tires have also been used to form the face of reinforced soil structures, using a similar technique to the residential wall construction with geosynthetic reinforcement placed between the tire layers. This technique has been used to construct rockfall barriers as shown in Figure 2.1, with the tire facing providing significant energy dissipation.

Whole tires have also been used as a means of reinforcement in soil slopes and retaining structures in the United States, France, and other countries since approximately 1976 (O’Shaughnessy and Garga, 2000). In these applications, layers of whole tires are tied together by polyethylene ropes or cables, and function as a reinforcement layer (similar to geotextiles and geogrids) to provide adequate tensile and shear strength that stabilizes the soil mass. In the particular project completed by O’Shaughnessy and Garga (2000), ‘tire mats’ were placed with a



Figure 2.1 Geosynthetic reinforced soil (GRS) rockfall barrier with tire facing in New Mexico (Christopher, 2002)

vertical spacing of 0.5 m (1.6 ft). In a manner similar to the design of soil slopes reinforced with geosynthetics, limit-equilibrium methods were used to analyze the reinforcing effect of the waste tires. The same failure mechanisms that apply to soil slopes reinforced with geosynthetics were analyzed, including pullout and breakage of the tire mats.

2.2 Tire pieces and tire shreds

Currently, waste tire pieces and tire shreds are predominantly more common in civil engineering applications than their whole tire counterparts. One example of the applications for tire pieces, although somewhat limited, is the construction of blasting mats using tire pieces tied with bailing wire. These heavy mats are often used in blasting projects to reduce flying debris and subsequent damage to nearby structures. The tire mats are placed on the soil surface around the blast area providing a surcharge that prevents projectile debris otherwise generated from the blast energy.

The most common form of waste tire products currently in use in civil engineering and transportation applications is the use of tire shreds as an engineered fill material. Tire shreds have been utilized in numerous embankment and wall applications due to the beneficial properties of lightweight, shear and tensile strength, drainage, and thermal insulation value. In landfill applications tire shreds have been used to insulate landfill liners (Benson et al., 1996) and as subgrade insulation material (Eaton et al., 1994). Tire shreds have also been used to provide drainage layers, daily cover, and support for final cover and leach fields in landfills.

The potential use of tire shreds as lightweight fill material represents one of the most significant means of use of waste tire products in civil engineering applications. (Bosscher et al., 1993). The use of tire shreds had a temporary setback in the mid 1990s due to concerns relating to potential exothermic reactions. However, the current design and construction guidelines (ASTM D6270) for use of tire shred fills address the issues that can promote an exothermic reaction, primarily by reducing the thickness of tire shred fill zones, controlling the size and cleanliness of the tire shreds, limiting the amount of exposed steel wires, and limiting the access of air and water to the tire shreds. The guidelines focus on limiting the amount of exposed steel and the environmental conditions which support corrosion and rusting of exposed steel.

As noted in ASTM D6270, the current design guidelines for tire shred fills include:

- Use tire shreds free of contaminants.
- Eliminate tire shreds which have been subjected to a fire.
- Specify and test the gradation and size of the tire shreds and limit the amount of granulated rubber.
- Specify and test the amount of exposed steel and metal particles.
- Minimize infiltration of soil and organic matter into the tire shreds by use of mineral soil covers and geosynthetic separation materials.
- Provide geotextiles as separation fabrics between mineral soil and a tire shred zone.
- Limit tire shred thickness to 1 m (3.3 ft) in Class I tire shred fills and 3 m (9.8 ft) in Class II tire shred fills.
- Mineral soil layers between tire shred zones should be at least 0.6 m (2 ft) thick and consist of soils having at least 30 % fines and no organic materials.

- Soil cover layers on the side slopes of tire shred fills should be at least 0.5 m (1.6 ft.) thick.
- Drainage outlets at the base of tire shred zones, or weep holes in retaining wall, must be designed and constructed to reduce air movement into the voids in the tire shreds fill zone.

ASTM D6270 indicates that tire shreds can and should be manufactured in sizes ranging from 4.75 mm-(0.18 in.) to 300-mm (12 in.) sieve sizes. The shreds are then graded and placed to minimize conditions favorable for exothermic reactions. *Class I* fills are defined as tire shred fills less than 1 m thick and *Class II* fills are defined as tire shred fills which range from 1 to 3 m thick. The gradation requirements for *Class I* fills are:

- a maximum of 50 % by weight passing the 38-mm (1.5 in.) sieve and
- a maximum of 5 % by weight passing the 4.75 mm sieve (0.18 in.).

and, the gradation requirements for *Class II* fills are:

- a maximum of 25 % by weight passing the 38-mm (1.5 in.) sieve and
- a maximum of 1 % by weight passing the 4.75-mm (0.18 in.) sieve.

ASTM D6270 indicates that no special design features are required for Class I fills. However for Class II tire shred fills, the material requirements include:

- tire shreds shall be free of fragments of wood, wood chips, and other fibrous organic matter.
- tire shreds shall have less than 1 % by weight of metal fragments which are not at least partially enclosed in rubber, and
- metal fragments that are encased in rubber shall protrude no more than 25 mm (1 in.) from the cut edge of the tire on 75 % of the pieces and no more that 50 mm (2 in.) on 100 % of the pieces.

2.3 Soil and tire shred mixtures

Recently, a small number of projects have studied the use of soil/tire shred mixtures as embankment fill material (Hoppe, 1998), including research involving the use of tire shred-soil mixtures (Zornberg et al., 2003). Tire shred-soil mixtures minimize concerns associated with exothermic reactions within the tire sheds only fill material as well as increase the shear strength of the soil being used.

2.4 Tire bales

The beneficial reuse of waste tires in the form of tire bales in civil engineering applications has recently gained interest. Tire bales appear to a likely alternative in many of the applications where whole tires and tire shreds have been used. The use of tire bales appears to facilitate construction operations and tire bales are believed to reduce the potential fire hazards associated with tire shreds. Tire bales are fabricated and installed as large blocks and generally do not require the spreading and compaction efforts required for tire shred and geotechnical materials. The potential for an exothermic heating causing a fire hazard in tire bales is reduced because steel belts and reinforcement of whole tires have very limited exposure to oxidation in the final product and the smaller sizes of tire shreds are not present in the tire bale. The absence of large quantities of exposed steel also implies that tire bales can be stored with less concern for moisture content and weather exposure, which causes corrosion of the exposed steel in a tire shred product.

Because the practice of embankment construction with tire bales is not well established, the current design approach and details are still somewhat “experimental”. The “experimental uses” of tire bales to date constitute significant achievements and show promising potential for increase their use as described later in this report. The potential use of tire bales is substantial as shown in the applications summary contained in Table 2.1. The technical feasibility of tire bale use expressed in Table 2.1 is based on the literature review performed for this study and the authors’ opinions. However, further research is recommended in Section 9 and 10 of this report to demonstrate the suitability of tire bale embankments in transportation systems, as well as to provide design and construction guidelines for use in future projects.

Table 2.1 Reported and possible uses of tire shreds, whole tires, and tire bales.

REPORTED AND POSSIBLE USES	Tire Shreds	Whole Tires	Tire Bales
WALL SYSTEMS			
Residential	Feasible as fill for Geosynthetic Reinforced Soil (GRS) Retaining Walls	Feasible with soil filler, connections, & facing	Feasible, with facing (e.g., shotcrete)
Commercial	Feasible as fill for GRS Retaining Walls	Feasible with soil filler, connections, & facing	Feasible, with facing
Sound Barriers	Feasible as fill for GRS Sound Barriers	Feasible with connections & facing	Feasible, with or without facing
Small Site Retaining Walls	Feasible as fill for GRS Retaining Walls	Feasible with connections, separation geotextile, & facing (CalTrans in 1988)	Feasible, with or without facing
Rockfall Barriers	Feasible as fill for GRS Retaining Walls	Feasible with connections & facing	Feasible, with or without facing
Culvert Headwalls	No	Feasible	Feasible, with or without facing
Large Building Blocks: Tire Bales Encased in Concrete	Feasible	Possible, but feasible	Feasible
SLOPE SYSTEMS			
With Layered Geo-synthetic Reinforcement	Feasible	Feasible with connections	Feasible
Repair Slope Failures	Feasible	Feasible with connections	Feasible
Lightweight fill	Feasible	Feasible	Feasible
EMBANKMENT CONSTRUCTION			
Lightweight Fill	Feasible	Feasible with in filling	Feasible
SUBGRADE STABILIZATION			
Mat for Roads Over Very Soft Foundation Soils	Feasible	Feasible with in filling	Feasible
Insulation to Reduce Frost Action	Feasible	Feasible with in filling	Feasible
Edge drains	Feasible	Not feasible	Feasible

Table 2.1 Reported and possible uses of tire shreds, whole tires, and tire bales (continued)

OTHER SYSTEMS			
Drainage Zones in Landfills	Feasible, with separation geotextile	Feasible, with separation geotextile	Feasible, with separation geotextile
Mix with Soil to Improve Shear Strength and Reduce Unit Weight	Feasible	Feasible	Feasible as inclusions or zones in an embankment
Erosion Protection for Water Edges w/ Shotcrete	Not Applicable	Feasible, with cables	Feasible with and without shotcrete or concrete facing
Erosion Protection for Swales and Channels w/ shotcrete	Not Applicable	Feasible	Feasible
Blasting Mats	Feasible	Feasible	Feasible
Low-cost Culvert Structures	Not Applicable	Feasible, tied to form a cylinder	May be Feasible
POTENTIAL USES			
Crash Barriers	Possible	Feasible with ties	Feasible
Temporary Dikes, Dams	May be feasible	Feasible, w/geomembrane wrap	Feasible, w/geomembrane wrap
Storm Water Detention Systems	Feasible, but small storage capacity	Feasible	Feasible

2.4.1 Selected case histories

The case histories in Appendix B illustrate and describe three different types of embankment projects in transportation applications. A brief description of each case history follows.

Case Study 1 describes the use of tire bales as strong lightweight fill in the repair of a side slope failure on a compacted fill embankment in Texas. The initial slope failure for this project was initiated by above average rainfall. Reconstruction, carried out in 2002, required the use of 360 tire bales, totaling about 36,000 scrap tires. Remediation of the slope failure began with placement of the delivered tire bales at the toe of the slope. Once the bales were secured, the slope was completely covered with soil, followed by reshaping of the slope. Compost and seed

were spread to stimulate vegetation growth and minimize future surface slope erosion. (TXDOT, 2003) Within the eight months following placement of the first bales, the Fort Worth area experienced nearly 50 inches of rainfall. A site visit and a preliminary slope stability analysis revealed that the use of tire bales instead of reconstructed a soil embankment had improved the factor of safety by 2 to 3 times.

Case Study 2 describes the reconstruction of a roadway using tire bales as lightweight embankment fills and insulation of frost-susceptible subgrades on segments of county roads in Chautauqua County, south of Buffalo, New York. The initial project in 1999 involved the excavation of 1000 feet of the existing road sub grade, and replacing it with tire bales. After excavation, a nonwoven geotextile was placed over the in-situ soil. Tire bales were then placed on top of this geotextile in a “brick-like fashion” to form the core of the roadbed structure. Voids between and within the tire bales were filled with coarse sand, which was compacted using traditional methods (a vibratory roller was used). Finally, three 6-inch thick gravel layers were placed and compacted, using vibratory rollers, on top of the tire bales to provide the unpaved roadway section.

After the first winter following completion of construction of the test section of the road, the results indicated that the test section performed much better than the rest of the road. Significant damage was observed at several locations along the rest of the road, while no damage was observed along the tire bale test section. This application of tire bales has continued since 1999 and by the end of 2004 the County expects to complete a total of five road bed stabilization projects, using a total of approximately 6,240 tire bales. The current rate of tire baling and use of tire bales to rehabilitate selected problematic low traffic volume roads matches the annual whole tire scrap rate in the county. The tire baling effort utilizes prison labor to fabricate the tire bales and reduce costs. (Chautauqua County, Ken Smith, Personal communication, 2004). The New York State Department of Environmental Conservation has given the County a Beneficial Use Designation which allows the County to only submit drawings and plans for tire bales in roadway embankment for project approval. (Chautauqua County, Kate Hill email to Dr. Naser Abu-Hejleh, dated 02 Jul 2003).

Case Study 3 describes embankment construction to provide grade separation for an access road and improved land usage at the Front Range Tire Recycling Facility in Sedalia, Colorado. Construction of the road involved an initial excavation into the slope (i.e. a “cut” excavation), to provide a relatively flat surface to support the tire bales. Next, the tire bales were stacked in a “brick-like” fashion using a forklift. Once the stacked bales reached the desired height for the roadway, the bales were compacted using a front-end loader. In addition to soil, tire shreds were spread over the surface of the tire bale layers in an effort to level the roadway. Finally, soil was placed in uniform layers above the final layer of tire bales and compacted.

Visual inspection of the access road indicates that the structure has performed very well so far, with little need for maintenance. The only reported maintenance needed involved the repair of small sinkholes that developed near the edges of the roadway. The mechanism for sinkhole generation is attributed to incomplete filling the voids of the tire bales with soil. As a result of the good performance of the first tire bale road, additional tire bale roads are being constructed.

2.4.2 Other transportation applications

Other transportation related applications which are expected to show a high benefit to cost ratio include situations where tire bales are used to provide improved subgrade support, embankments for roadway structures, backfill materials for bridge abutments, retaining walls, sound barrier walls, and rockfall barriers. For example, tire bales were used as the core of a retaining wall along 1,220 m (4,000 ft) of the Pecos River in Carlsbad, New Mexico.

2.4.3 Need for additional research

Even though there have been a number of “experimental” tire bale civil engineering applications similar to the case studies described above, there is a need for additional research. Nearly all of the civil engineering projects that have utilized tire bales to date have been completed on a “trial” basis. This method has apparently proven to be very successful in most cases.

Several concerns have been raised about the use of tire bales in embankment applications, based on the experience of tire shred fills. The concerns include:

- potential for significant exothermic reactions.
- appropriate fire protection requirements.
- potential impacts on groundwater quality.
- permeability and drainage characteristics.
- potential buoyancy problems for flooded embankments.
- long-term compression and creep rates.
- the need for long-term integrity of tie systems or methods.
- internal and external shear strengths.
- requirements for soil buffer, or soil cap layers.
- requirements for exterior protection and facing materials.
- requirements for ancillary materials such as geotextiles (for filter and separation requirements), geomembranes (for separation and barrier requirements), and geogrids for reinforcement requirements.

These issues and their relative importance for selected tire bale applications are discussed and in most cases addressed in Sections 3 to 10. Items requiring additional study are included in the field study and implementation plan proposed in Sections 9 and 10. The proposed field research is important to extend the knowledge of tire bale properties and capabilities, efficiently design all tire bale projects with adequate factors of safety, and ultimately make tire bales available as an accepted material on a large scale for civil engineering applications.

3 CHARACTERISTICS OF WASTE TIRES, TIRE SHREDS AND TIRE BALES

Previous studies have evaluated the engineering properties of the various waste tire products used in civil engineering applications. This has involved both laboratory and field programs. Findings from these studies, which have generally focused on the thermal and the mechanical properties of waste tire products, are summarized herein.

3.1 General characteristics of rubber tires

Rubber tires manufactured for passenger cars and trucks have the following typical composition:

(See Appendix C and www.rma.org/scraptires/scraptiremarkets/scraptirecharacteristics/)

<u>Material</u>	<u>% by Weight</u>
Natural Rubber	14
Synthetic Rubber	27
Carbon Black	28
Steel	14 – 15
Fabric, fillers, etc	16 – 17

A typical weight is approximately 110 N (25 lb) for new automobile and light truck tires and 556 N (125 lb) for new truck tires. The average weight of scrap automobile tires is 89 N (20 lb) and 445 N (100 lb) for truck tires. When scrap tires are stored in piles, the approximate number of tires per cubic yard has been reported (Appendix C and email communications on EPA website regarding tire conversion rates: www.epa.gov/jtr/jtrnet/tireconv.htm):

<u>Condition</u>	<u>Auto Tires (Tires/yd³)</u>	<u>Truck Tires (Tires/yd³)</u>
Loose	8.5	3
Medium	10	3.5
dense	12	4

Rubber is characterized by its comparatively low thermal conductivity. Some research has already been conducted on the thermal characteristics of waste tire products. The ability of tire shreds to serve as subgrade insulation, due to their low thermal conductivity, was illustrated by a field study in New Hampshire (Eaton et al., 1994). The thermal characteristics of tire shreds were also evaluated as part of a field study regarding insulated landfill liners (Benson et al., 1996). Laboratory tests that have quantitatively characterized the thermal conductivity of tire

shreds have generally indicated it to be below 12% of that for typical soils (Humphrey et al., 1997). Thermal diffusivity of whole tires has also been studied by the Colorado School of Mines (Shock et al., 2001). A field monitoring program is underway at the University of Texas at Austin to evaluate the thermal properties of waste tires and tire/soil mixtures.

3.2 Characteristics of tire shreds

A number of laboratory and field studies have been conducted that illustrate the engineering properties of waste tire products, particularly tire shreds. Tire shreds were first used as lightweight fill material to replace a conventional fill and to reduce settlement of a soft organic foundation soil (Geisler et al., 1989). Since then, numerous projects have utilized tire shreds as a homogeneous monofill zone to replace mineral soil and aggregate in road embankments (Bosscher et al., 1993; Bosscher et al., 1997; Hoppe, 1998; Dickson et al., 2001, and Baker et al., 2003). These studies indicate that the structural performance of embankments, which are properly designed and constructed with tire shreds, can be as good as or at least comparable to that of soil-only embankments.

Laboratory studies have been conducted to determine to the basic engineering properties of tire chips and soil/tire mixtures. Humphrey and Manion (1992) completed an early study in which characteristics of tire shreds such as the specific gravity, compacted unit weight, compressibility, and coefficient of lateral earth pressure at rest were determined. The shear strength of tire shreds was studied by conducting triaxial tests and direct shear tests. Humphrey (1998) presents failure envelopes of direct shear tests of tire shreds at low stress levels. The envelopes for normal stresses less than 100 kPa (2000 psf), are characterized by a 4 kPa (80 psf) “adhesion” intercept and a concave downward curved envelope with friction angles in the range of 25 to 30 degrees. This data was reported in 1992 to 1995 for eight laboratory tests of tire shreds sizes ranging from 9.5 mm to 75 mm (3/8 in to 3 in.) in 305 mm to 405 mm (12 to 16 in. shear boxes.)

The compaction characteristics, compression behavior, shear strength, and hydraulic conductivity of tire chips and soil/tire chip mixtures were studied by Edil and Bosscher (1994). Humphrey (1998) presents a summary of the results of laboratory tests of the vertical strain compressibility of tire shreds and the design procedure to estimate the compressibility of a tire

shred fill and to compute the amount of overbuild required to compensate for the short-term settlement of tire shred fills during construction, and up to two months following placement of the tire shred fill. The short-term construction settlement of tire shreds is usually less than the laboratory test values on 75 mm (3 in.) shreds, which indicates a 10 to 25 % strain for vertical stresses ranging from 1 to 5 psi (Humphrey, 1998). This settlement is usually addressed by (1) constructing an “overbuild zone” equal to, or somewhat larger than, the estimated settlement, and (2) applying a temporary surcharge to accelerate tire shred settlement and “over consolidate” the tire shred embankment. The secondary, or long-term creep settlements have generally been less than 1 percent of the height of the tire shred zone (Baker et al., 2003). Tire shred settlement is usually monitored by survey of settlement platforms during and following construction to confirm the embankment performs as expected. Temperatures inside the tire shred zone are often monitored to check the potential for exothermic reactions.

The engineering properties of a soil/tire shred mixture including 50% Ottawa sand and 50% shredded tires by volume were studied by Masad et al. (1996). This study illustrated the ability of tire shreds to significantly increase the shear strength of soil. This finding is supported by the findings of Foose et al. (1996) in a study that determined the friction angle to increase from 34 degrees for unreinforced Portage sand to as much as 67 degrees when reinforced with tire shreds. A recent study was conducted using a large scale triaxial apparatus with the goal of evaluating the optimum dosage and aspect ratio of tire shreds within granular fills (Zornberg et al., 2003). The effects on shear strength of varying confining pressure and sand matrix relative density were also evaluated. The tire shred content and tire shred aspect ratio were found to influence the stress-strain and volumetric strain behavior of the mixture. The axial strain at failure was found to increase with increasing tire shred content. Except for specimens of pure tire shreds and soil with comparatively high tire shred content, the test results showed a dilatant behavior and a well-defined peak shear strength. The optimum tire shred content (i.e., the one leading to the maximum shear strength) was approximately 35%. For a given tire shred content, increasing tire shred aspect ratio led to increasing overall shear strength, at least for the range of tire shred aspect ratios considered in this study. The shear strength improvement induced by tire shred inclusions was found to be sensitive to the applied confining pressure, with larger shear strength gains obtained under comparatively low confinement.

3.3 Characteristics of tire bales

3.3.1 Tire bale fabrication

Tire bales are fabricated by a lightweight tire baling machine, which is readily transportable and easily moved by towing with a truck. It should be noted that some cardboard baling machines have been used for forming tire bales. This practice is questionable because a cardboard baler may not be designed for the loads and stresses associated with “conventional” machines specifically designed for baling scrap tires. (Encore Systems, Inc.). The baling machine typically compresses approximately 100 waste auto tires into a 1.5 m³, 0.9 metric ton (2 cubic yard, 1-ton) bale. Tires are usually “laced” with half the tires overlapped in each layer prior to compression and tying. Each bale is typically fastened with a series of galvanized or stainless steel baling wire (Encore Systems, Inc.). Tire baling results in a 5:1 volume reduction of loose tires. Figure 3.1 shows a typical tire bale with tires that have been laced.



Figure 3.1 Typical tire bale

When truck tires are included with auto tires, each truck tire is considered to be equivalent to five (5) automobile tires and that bale is described as 100 passenger tire equivalent, or “100 pte” (Gilbert email). Truck tires can be cut to remove the sidewalls from the tread. The sidewalls and treads have been used to fabricate construction barrels (Encore, 2004).

It has been reported that one tire baling machine can process 600,000 tires per year in a 1-shift per day operation (Encore, 2004). This is equivalent to 25 bales per day for a 12 month, 20 day per month operation. Other processors report 4 to 6 tire bales per hour, or approximately 40

bales per day. Tire bales can also be fabricated to produce ½ and ¾ size bales, or to make tire bales larger (and heavier) than a typical 1.5 m³, 0.9 metric ton (2 cubic yard, 1 ton) tire bale. Some of the smaller bales have been encased with concrete (Northern Tyre, 2004). Typical tire bales can usually be easily moved and placed using a forklift.

In some applications, the tire bales are required to be linked together to avoid shifting after placement in the field and improve shear resistance. In this case, the tire bale can be manufactured with a steel pipe positioned in two directions through the middle of the bale (Encore, 2004.). After placement of the tire bale in the final location, an aircraft cable can be routed through the pipe and bolted at the end of the last bale, or clamps can be used to fasten the pipes of adjacent bales together. This allows the connection of several tire bales together. Stacking arrangements, the use of concrete, flowable fill, and inclusion of geosynthetic or metallic reinforcement can also provide beneficial interlocking characteristics to maximize interface shear resistance of tire bales and reduce post-construction movements.

The typical physical characteristics including the dimensions and weights for compacted tire bales as reported in the literature reviewed for this report are shown in Table 3.1.

Table 3.1 Typical physical characteristics of tire bales.

Physical Properties (1)	Typical Values (1)	Range (1)
Number of Automobile Tires Number of Truck Tires	100 20 (=100 pte)	90 to 120 20 to 25
Approximate Dimensions (vary with baler and operation)	0.75 m x 1.4 m x 1.5 m (2.5 ft x 4.5 ft x 5 ft)	½ bale, ¾ bale and full bale
Approximate Volume	1.5 m ³ (2 yd ³)	0.75 to 1.5 m ³ (1 to 2.1 yd ³)
Approximate Weight	8.9 kN (2000 lb)	4.5 to 13.3 kN (1000 to 3000 lb)
Approximate Unit Weight	5.5 kN/m ³ (35 pcf)	5.5 to 8.9 kN/m ³ (35 to 53 pcf)

Note 1. Numerical values for dimensions, volume, and unit weight depend on the spacing of measurements made around the non planar outer sides of a tire bale (see Figure 3.1).

3.3.2 Tire bales as engineered lightweight fill

Tire bales are classified as an Engineered Lightweight Fill (E.L.F.) material. As noted in Table 3.1, the unit weight of a typical tire bale is approximately 5.5 kN/m^3 (35 lb/ft^3), and comparable to a reported unit weight of 5.3 kN/m^3 (40 lb/ft^3) reported for compacted tire shreds. As the typical dry unit weight of tire bales is approximately 30 % of the weight of typical soils, tire bales become a candidate for use in a situation where a lightweight fill is required for economic and stability reasons and possibly eliminate the need for foundation improvements on soft ground sites. However, other engineering properties including in situ unit weight, compressibility, strength, and time-dependent response of the tire bales are required to evaluate the anticipated performance of a tire bale embankment before tire bales can be used on major highway projects. The tire bale projects completed to date indicate successful applications, but careful monitoring of several projects is necessary to assess and confirm that the long-term performance of tire bales is satisfactory and in accordance with design assumptions.

3.3.3 Tire bale properties

Tire bale properties have generally been qualitatively characterized by the manufacturer of the tire baler, or by limited tests of individual tire bales in a laboratory setting. Although some basic physical characteristics of tire bales have been evaluated as shown in Table 3.1, little information has been reported on the mechanical properties of tire bales which are of interest for civil engineering applications. The engineering properties of in situ tire bales will depend on:

- Mechanical and hydraulic systems of a particular tire baler.
- The size and type of tire, including partial cutting of tires used in a bale.
- Methods used to stack, and the loads used to compress, tires in the baler chamber during each stage of tire bale fabrication.
- The restraining system including the type of tie—wire, strap, or cable, the number of ties applied to a bale, the tensile load applied to the tie, and the fastener.
- The in-service placement geometry for the tire bales, and any connection systems used to develop a tire bale embankment zone.

- The interaction of the surrounding soil/rock/geosynthetic materials which form the matrix within and around the in place tire bales.
- Internal and external physical, mechanical, and hydraulic characteristics (e.g., density, strength, and permeability, respectfully).
- Long-term durability issues for both the tires and the ties used to fabricate the bales.

Due to the compression load and side restraint used by the baling machine to compress tires in the compaction chamber, and the restraint the tie system places on the compressed tires, free-standing tire bales and tire bales installed in an embankment are expected to show a higher shear strength and modulus than other waste tire products. However, short and long-term compressibility of tire bales is one property that deserves further investigation. The compressibility, strength, and time-dependent response of tire bales have not been extensively quantified to the extent necessary for engineering design. Up to 2004 only a few laboratory and field tests on tire bales have been reported, and those tests provide only very limited results, especially considering the potential variability of tire bales, either as manufactured, or in situ where the bale is filled with, or surrounded by, other materials.

The first available laboratory test report, conducted by the Twin City Testing Laboratory for a Minnesota Department of Transportation project, is dated March, 2000 and included in Appendix C.2. The report describes one unconfined compression test and a short-term (3-day) creep test on one tire bale. The limited nature of this study, and the absence of other test data to define the basic engineering properties of tire bales, led to a comprehensive laboratory testing program that was conducted as part of this study and is described in the next section.

Manufacturers of tire bales have generally reported a good bearing capacity for fabricated tire bales. For example, Central States Tire Recycling of Nebraska conducted a study that evaluated the effect of a static load applied to an “Enviro Block” type tire bale. This study showed that loads equivalent to a “fully loaded semi trailer” (dimensions and weight not reported) caused minimal distortion to the “Enviro Block.” The loads were reported to have not compromised the structural integrity of the bale.

The American Society for Testing and Materials has published a “Standard Practice for Use of Scrap Tires in Civil Engineering Applications” (ASTM D6270-98) that provides guidance on the use of scrap tires in the form of tire shreds. Some of the data and guidance has applicability for tire bales used in place of, or along with, stone, gravel, soil, sand or other types of fill.

Tire bales are used in association with other materials. Compacted soil layers have been constructed beneath, between, and above layers of tire bales with the intent to fill voids within or around the tire bales. Tire bales have been reported to maintain their structural integrity in association with surrounding soil layers. In one case the soil matrix around tire bales has exhibited small “sink holes” where subsequent compaction and construction traffic (and possibly precipitation) may have caused internal movement of the soil matrix into voids within the tire bales/soil embankment zone (see Case Study 3 in Appendix B.3). In another example, some applications have used shotcrete, which was applied after installation of the tire bales to provide a facing layer as well as protect and consolidate the tire bale zone. The use of shotcrete reportedly has not caused long-term negative effects on the tire bale performance.

Tire bales have been used in civil engineering and embankment projects for more than 14 years with no reported biological or chemical degradation. However, the authors are not aware of any reports on tire bales, which have been exhumed and subjected to laboratory testing. In addition, the anticipated longevity of tire bales in the various application environments, aging factors and environmental factors that may be detrimental to their use have not been documented.

3.4 Evaluation of potential exothermic reactions in tire bales

The internal heating observed in tire shred embankments raises a similar concern for tire bales. The potential exothermic reaction of tire bales is evaluated in this section and is based on the design guidelines for tire shred fills that were developed in 1997 to reduce significant internal heating created by exothermic reaction in tire shred fills. The guidelines were developed in response to three spontaneous internal fires in tire shred embankment fills greater than 8 m (26 ft) thick in 1995.

An Ad-Hoc Civil Engineering Committee prepared “Design Guidelines to Minimize Internal Heating of Tire Shred Fills”. This committee, composed of members from industry, government, and academia, was jointly sponsored in 1995 by the Scrap Tire Management Council and the International Tire and Rubber Association Tire and Rubber Recycling Committee to produce a set of guidelines so that scrap tire use could continue. The principal author was Dr. Dana Humphrey, currently at the University of Maine. The design guidelines were issued by the FHWA in 1997 as a memorandum which stated the guidelines were conservative. These guidelines were adopted by ASTM as a recommend standard of practice in 1998 (ASTM D 6270). The ASTM requirements for tire shred fills are listed below in Column 1 of Table 3.3. For comparison, the preliminary requirements for tire bales placed in a transportation application are listed in Column 2 and a qualitative relative comparison of the requirements for tire bales versus tire shreds are listed in Column 3.

Table 3.2 Preliminary application of tire shred guidelines to tire bale embankments

Guidelines to Reduce Exothermic Reactions in Tire Shred and Tire Chip Embankment Fills (ASTM D 6270)	Apply Column 1 Guidelines to Tire Bale Embankments (Preliminary)	Compare Column 2 to Column 1 (Preliminary)
G.1 Cut/shred all tires to: a) largest piece is less than a quarter circle in shape, b) less than 0.6 m long, and c) one sidewall is severed from the tire tread	Fabricate tire bales with whole tire, or allow maximum % of cut tires. (Note 7)	Not required & no cost for tire bales.
G.2 All tire shreds shall be free of contaminants that could create a fire hazard (Note 1)	Monitor visually, remove or clean contaminated tires.	Same requirement
G.3 Eliminate all tire shreds that contain remains of tires subjected to fire. (Note2)	Monitor visually, remove or clean contaminated tires.	Same requirement
For CLASS I Fill (< 1 m thick) of Tire Shred or Tire Chip Materials	(Note 8)	
I.1. Maximum of 50% (by wt) pass 38 mm (1.5 in) sieve (Note 3)	Not Applicable	No cost for tire bales
I.2. Maximum of 5% (by wt) pass 4.75 mm (0.18 in) sieve (Note 3)	Not Applicable	No cost for tire bales
For CLASS II Fill (1 – 3 m thick) of TS-TC Materials (Note 4)		Note 7
II.1. Maximum of 25% (by wt) pass 38 mm (1.5 in) sieve. (Note 3)	Not Required	No cost for tire bales
II.2. Maximum of 1 % (by wt) pass 4.75 mm (0.18 in) sieve. (Note 3)	Not Required	No cost for tire bales

Table 3.2 Preliminary application of tire shred guidelines to tire bale embankments (continued)

II.3 Tire shreds free of wood fragments, wood chips, and other organic matter. (Note 1)	Monitor visually & clean to remove organics	Same requirement
II.4. Maximum of 1 % (by wt) of metal fragments that are not at least partially encased in rubber. (Note 3)	Not Required	No cost for tire bales
II.5 Metal fragments partially encased in rubber shall protrude no more than 25 mm (1 in.) from the cut edge of a tire shred on 75 % of the pieces and no more than 50 mm (2 in.) on 100 % of the pieces. (Note 3)	Not Applicable (Tire bales are fabricated using whole tires, or a maximum percent of cut tires.) (Note 8)	No cost for tire bales
II.6 Minimize infiltration of water into the tire shred fill. (Note 5)	Not Applicable	No cost for tire bales
II.7 Minimize infiltration of air into the tire shred fill. (Note 5)	Not Applicable	No cost for tire bales
II.8 No direct contact between tire shreds and soil containing organic matter, such as topsoil. (Note 6)	Geotextile is not required to reduce exothermic reactions, but used to provide separation.	Limited cost increase for tire bales Limited contact of exposed steel to organics in a tire bale
II.9 Tire shreds/chips shall be separated from the surrounding soil by a geotextile. (Note 6)	See above note, not needed on subgrade	Limited cost for tire bales
II.10 Avoid drainage features at bottom of the tire shred chip fill that provide air free access to the fill. (Note 5)	Not Applicable	No cost for tire bales
Notes		
<ol style="list-style-type: none"> 1. Implies specification to visually monitor and remove unsuitable materials as needed. 2. Implies specification to visually monitor and segregate unsuitable materials as needed. 3. Requires visual monitoring, sampling, and laboratory testing for verification. 4. A 0.6 m (2 ft). thick layer of soil is typically placed between each 3 m (10 ft) or less, thickness of tire shred fill. 5. Requires: (a) sealed geomembrane to encapsulate the tire shred zone and (b) back flow seals on bottom drains. 6. Requires geotextile, geomembrane, or a 6 in. minimum thick layer of soil as separator/filter material. 7. The maximum thickness of Class I and II Tire Bale Embankments has not been determined. 8. The allowable percentage of cut tires has not been determined. 		

To summarize the evaluation in Table 3.2, the application of the ASTM D 6270 tire shred guidelines to a tire bale fill would indicate that three (3) of the 15 tire shred fill guidelines should be applied to a tire bale fill. The three guidelines generally applicable to a tire bale fill relate to monitoring and removal of contaminants and tire pieces that had been subjected to a previous fire and could cause a fire hazard. In addition the separation requirement for tire shreds in II.8 can be provided by a geotextile between tire bales and adjacent soils instead of a layer of mineral soil.

In reference to Note 8 in Table 3.2, it is the authors' opinion that the maximum thicknesses of a Class I and a Class II tire shred fill in ASTM D 6270 are conservative for tire bales and may ultimately be somewhat larger than the maximum thicknesses of 1 m (3.28 ft) for a Class I tire shred fill, and approximately 3 m (10 ft) for a Class II tire shred fill. The specific requirements for each class will require further evaluation in prototype field applications as recommended later in Sections 9 and 10.

The ASTM D 6270 guidelines primarily cover in-situ application issues. Other ancillary operations also require control including processing whole tires into compacted tire bales, pre-placement handling, storing and stockpiling, hauling, and installing the tire bales. However, the guidelines provide the basis for project specifications, which should be prepared specifically for each tire bale project to address both the design issues and the ancillary issues that are the responsibility of the material supplier and contractor.

Some of the fire protection and safety issues relating to storage of scrap tires and operation of tire recycling facilities have been codified. Plans for scrap tire processing operations are typically reviewed and permitted by local and state fire marshal officials. Examples of fire protection codes and fire protection/safety policies and requirements are discussed below.

3.4.1 Regulatory guidance for storing scrap tires

In addition to the ASTM D 6270 design and construction guidelines to reduce exothermic reactions in tire shred fills, requirements to reduce and control fire hazards associated with storage of new whole tires, scrap tires piles, and tire shreds have been evaluated by a number of agencies. The documents would apply to permanent and temporary tire bale stock piles, both at the fabrication facility and at the construction site, and include:

1. The Colorado Department of Public Health and Environment, State Board of Health/Hazardous Materials and Waste Management Division regulations pertaining to Recycling Facilities in 6 CCR 1007-2, Section 8 and Scrap Tire Facilities in Section 10. Section 10 includes requirements for a fire control plan, tire pile storage dimensions, separation distances, and reporting fire incidents. (See Appendix G).

2. Title 14 California Code of Regulations Division 7 Integrated Waste Management Board (IWMB), Chapter 3, Article 5.5 titled Waste Tire Storage and Disposal Standards (Sections 17350 to 17356) includes a list of outdoor storage requirements and a table of minimum separations distances depending on the size and height of tire stockpiles. (See Appendix G)
3. The National Fire Protection Association, in NFPA 231D 1998, includes Guidelines for Outdoor Storage of Scrap Tires. NFPA 231 D primarily addresses code and fire protection requirements related to inside storage of rubber tires in warehouse and retail structures and the related fire protection systems. However, an appendix is included for information and is not a NFPA requirement. This appendix provides information on fire experience, separation of tire piles based on size and height of tire piles, fire department access to storage sites, site security, pre-incident planning, water supply, pile geometry, separation distances, and fire-fighting tactics and strategy for both whole tires and processed tire fires. Information in the document is similar to information provide in the California Code in Item 2 above.
4. The U. S. Fire Administration (1998) prepared Special Report 093 titled “Scrap and Shredded Tire Fires”, which examined seven case histories of typical tire fires. It summarizes key issues associated with the historical background of tire recycling, regulatory impacts, tire storage and processing conditions, and the supply – demand issues related to production of tire shreds and crumb rubber for highway applications. The report also discusses the issues and hazards related to ignition of tire materials, selection of materials and equipment to control and suppress tire fires, problems related to fire operations, and cleanup costs. The three stages of tire product combustion are described in the report and the difficulties of controlling and extinguishing tire fires. Depending on the strategy and approach tire fires can continue for days or months.

It should be noted that the U.S. Environmental Protection Association (EPA) does not consider scrap tires a hazardous waste. However, once there is a fire, the tire product breaks down in hazardous compounds including gases, heavy metals, and oils. The average auto tire is estimated to produce more than two gallons of oil which is a significant environmental pollutant that can move into groundwater and contaminate well water.

5. The California Integrated Waste Management Board (IWMB) has published an extensive training manual titled "Tire Pile Fires: Prevention, Response, Remediation" dated September 23, 2002. The manual focuses on California's history of tire regulation, fire prevention, response to tire fires, and post fire assessment and remediation.

3.4.2 Reports of tire bale storage requirements and fires

The number of available reports on tire bale storage requirements and tire bale fires is limited.

The only available paper providing a direct comparison of the effects of burning the three different types of scrap tires available to the authors at this time is a paper published in Interflam "96" March 1996, titled "Fire Safety Assessment of the Scrap Tire Storage Methods" (Williamson and Schroeder, 1996). This paper is also cited as a reference in NFPA 231D "Standard for Storage of Rubber Tires", 1998. The report describes three instrumented experimental fires conducted in September 1993 at a scrap tire yard in Tracy, California to compare whole tires, tire shreds, and small tire bundles (16 to 18 tires per 0.75 m (30 in.) long stacked, tied with 2 strands of wire and polymer cord).

The test, sponsored by the California State Fire Marshal's office, consisted of burning piles of each type with approximately 100 tires in each pile. Fire monitoring included measurement of flame height and change in heat flux with distance. The test data was analyzed with a computer program (Building Radiation Program Version 1 --BRAP1) in order to calculate the thermal radiation from an equivalent building fire. The program was then used to solve the configuration factor equation and relate the observed heat flux and temperature data to separation distances that would be required between scrap tire piles composed of three different tire materials. The calculation of a required minimum separation distances between storage piles was based on the maximum heat flux (10 kW/m^2) which would not ignite an adjacent target tire pile, and the maximum heat flux (5 kW/m^2) which human skin (fire fighters) can tolerate in normal turnout gear. The separation distance computed by these criteria was then compared with the California regulations.

Williamson and Schroeder (1996) include several observations and conclusions relating to open air storage of scrap tires. These are:

- Whole tires should be barrel stacked (because fires in horizontally stacked tires are much easier to control – (Williamson, personal communication 2004).
- Shredded tires reduce tire volume but exhibit rapid spread of surface flames.
- Piles of shredded tires should be placed on level ground, limited in size, and not placed against a wall or sloping hillside (to reduce rapid spread of surface flames).
- The bundled tires expanded in size when the tie wires and cords burned, reaching a size approximating the whole tire pile. (Note: The tire bundles were much smaller in size, and had approximately half of the compressed density of typical tire bales, and apparently used different tie materials than the typical tire bales described in Section 4 of this report.)
- The required minimum separation of tire piles is related to the height and length of tire piles.
- Minimum separation distances should also consider the impacts of a tire fire on air quality, wind conditions, and nearby occupants and use of the surrounding area.

The authors' personal communication with Mr. Rodney Slaughter, California Deputy State Fire Marshall (2004) indicates that tire bale fires in open storage facilities could be difficult to control and extinguish, more so than tire shreds apparently based on the results of the Williamson and Schroeder (1996).

3.4.3 Summary of fire protection evaluation

In summary, the issue of appropriate fire protection and design procedures to reduce the risk of fires involving tire bales is a complex issue that involves many conditions. Developing an appropriate approach to fire protection issues for tire bales requires consideration of the current regulatory guidance for tire storage, experience with fires in uncontrolled outdoor storage of whole scrap tires, and the observed success of tire shred fills designed and constructed in accordance with the ASTM 6270 design guidelines. The general experience with tire fires includes the following issues:

1. **Ignition sources.** Piles of whole tires and tire shreds occasionally burn as the result of unexpected human or natural events such as arson, adjacent small fires, and lightning strikes. Tire fires also start due to the presence of contaminants, organics, air, water, small sized rubber particles and shreds (placed in thin to thick layers) in uncontrolled tire stockpile and/or tire shred fills, which result in the oxidation of exposed steel and develop a significant exothermic reaction that ultimately reaches ignition temperatures which range from 400 to 1000°F. However, implementation of the ASTM D6270 guidelines for tire shreds indicates that controlling the factors that lead to an exothermic reaction can substantially reduce the risk of fires in tire shred fills, and no fires have been reported to date for those projects. In addition, tire bales (as illustrated in Table 3.2) do not inherently “fit” 13 of the 15 design guidelines for tire shreds. The tire shred guidelines for cleanliness, are considered initially appropriate for tire bales, but particle size criteria and limitations on air and water access for tire shreds are not currently considered a substantial requirement for tire bales because tire bales are inherently considered less susceptible to exothermic reactions than tire shreds.
2. **Tire Stockpiles** Current regulated practices for outdoor storage of whole tires and shredded tires is to control size of storage piles, provide and implement appropriate fire prevention practices, provide minimum separation between stockpiles, and restrict and control site access, etc. These practices should also be used for storage and transportation of tire bales until sufficient laboratory test data is available to justify modification of current practices and state guidelines for whole tires and tire shred fills which are already under the jurisdiction of local and state fire marshals as discussed above and codified in state codes and requirements.
3. **In-service Conditions** In-service conditions for tire bale embankments can be considered similar to typical tire shred embankments. However, the response and performance of tire bale materials is expected to be somewhat better than the inherent performance of tire shred embankments. As a starting point, some of the current ASTM 6270 guidelines for tire shred embankments could be appropriate guidance for tire bale fills. Field test sections and in-service temperature measurements are required to evaluate the benefits of soil covers for fire protection purposes and develop a feasible design approach for tire bale embankments that could include the use of soil barriers to form “fire walls” and limit the lateral dimensions of tire bale zones.

4 MEASURED PHYSICAL AND MECHANICAL PROPERTIES OF TIRE BALES FROM LABORATORY TESTS

The literature review and the authors' discussions with tire baler manufacturers and public works engineers who have used tire bales in embankment applications indicates that a very limited number of laboratory tests have been conducted to determine the engineering properties of fabricated tire bales for design purposes. The absence of test data to define the basic engineering properties of tire bales led to the performance of the 2004 laboratory testing program that is the basis for the tire bale properties including in this report. The following laboratory test program was developed to determine the essential material properties needed for the design and construction of embankments with tire bales. Results of each test are presented followed by a summary of tire bale properties as determined from the test results and literature review. This section concludes with a comparison of tire bale and other lightweight fill material properties.

The 2004 laboratory testing program consisted of performing laboratory tests on eight tire bales, fabricated by Front Range Recycling, Sedalia, Colorado. The tests were performed for CDOT by GeoTesting Express, Roswell, GA in 2004. The 2004 laboratory tests included measurement and evaluation of tire bale to determine typical values for the:

- Range and average geometry of the exterior surfaces of the tire bales.
- Range and average unit weight, both air dry and submerged.
- Vertical permeability
- Compressibility characteristics with both vertical and horizontal deformation measurements on tire bales.
- Confined compressibility of tire bales (with a dry sand infill materials), including static and cyclic modulus evaluation.
- Rebound and potential lateral expansive pressure.
- Time-dependent deformations of single bales under sustained load (i.e. creep) for up to 1,000 hours.
- External shear strength along the surface between two vertically stacked bales.

The detailed test procedures and results of these tests are presented in Appendix D. The following sections provide a summary of the test procedures and results for each of the tests performed.

4.1 Geometry of the exterior surfaces of the tire bales

Unit weight tests were made on all eight tire bale samples. The procedure consisted of volumetric measurements, weight of the sample as received, and noting any presence of moisture in the bale. The volume was measured by taking dimensional measurements of the height, width, and length of each tire bale. The height was measured with the bale lying on its flat base with the tires oriented in a vertical direction (as was shown in Figure 3.1). This position is also assumed to be the “vertical direction” for both laboratory testing and field placement. For dimensional measurements, a significant number of measurements were taken to obtain unit weight measurements within a 1 % accuracy and repeatability. Digital image analysis was used to confirm the measurements with two digital photos (front and side view) taken of each bale along with a visible reference scale mounted on the bale using a level camera located vertically at the mid height of the bale. Representative images are shown in Appendix D of this report. The typical measured dimensions were:

Height	0.7 ± 0.03 m	(2.3 ± 0.1 ft.)
Width (band direction)	1.46 ± 0.02 m	(4.8 ± 0.07 ft)
Width (cross-band direction)	1.55 ± 0.06 m	(5.1 ± 0.2 ft)
Volume =	1.59 ± 0.085 m ³	(56 ± 3 ft ³)

4.2 Dry, wet and submerged unit weight of “as received” tire bales

Two tire bales were stored in a dry environment for a sufficient period of time (i.e., no weight change within a 1 day period of time) in order to obtain an air dry unit weight for these two samples. These two samples were also used to obtain the submerged and wet unit weight of the tire bales. Submerged unit weight measurements were obtained by submerging the entire bale in a tank of water for a sufficient period of time to allow all free air to escape and obtain the weight below water. Prior to placement in the tank, the water in the tank was maintained at room

temperature for over 24 hours to reduce the amount of and equilibrate the dissolved oxygen in the water. After obtaining the submerged weight, each sample was extracted from the water, allowed to freely drain, and weighed immediately after drainage to obtain the wet unit weight. The following unit weights were determined for the tire bales tested:

Dry unit weight =	$5.74 \pm 0.47 \text{ kN/m}^3$ ($36.5 \pm 3 \text{ pcf}$)
Wet unit weight =	$6.21 \pm 0.31 \text{ kN/m}^3$ ($39.5 \pm 2 \text{ pcf}$)
Submerged unit weight =	$0.67 \pm 0.23 \text{ kN/m}^3$ ($4.3 \pm 1.5 \text{ pcf}$)

The submerged unit weight result indicates that tire bales do not float, which can be a major advantage in below water or flooding applications over lightweight fills which float (e.g., EPS).

4.3 Vertical permeability of tire bales

Note that the permeability of an in-place tire bale will vary in all three directions, and vary in different parts of the tire bale due to the heterogeneity of the tires and the void sizes and the adjacent infill materials. For embankment applications the vertical permeability, which defines flow vertically through stacked tire bales, is considered to be the most critical value due to drainage of infiltration seepage water and potential buoyancy during flooding. The vertical permeability of two tire bales was evaluated by rapidly extracting the bale, after it was submerged in a water filled tank, and then monitoring the time for water to completely drain from the tire bale under gravity flow. The horizontal sides of the tire bale were wrapped with a membrane before the bale was submerged to prevent lateral water flow from the sides of the bale as it was extracted from the tank. The time to extract the tire bale was sufficiently rapid to provide differential head between the water in the tank and the water level in the tire bale. About 75% of the water flowed out of the bale during extraction from the submerged condition in less than 1 min., indicating a permeability of greater than 0.1 cm/sec. After extraction, approximately 0.068 m^3 (2.4 ft^3) of free water remained in the bale based on the weight of water that drained from the bale. Approximately 90 % of the remaining free water was found to drain from the tire bales in 10 to 15 min. and practically all of the free water drained within 20 to 25 min. The measured flow rates indicate that tire bales have a relatively high intrinsic vertical permeability on the order of 0.05 to over 0.1 cm/sec, which is similar to that of gravel.

4.4 Compressibility tests with both vertical and horizontal deformation measurements

Compression tests on the tire bales were performed generally following the ASTM D2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. Figure 4.1 shows a photo of the test setup. The top and bottom loading platens consisted of large concrete slabs, with dimensions that extended in all directions beyond the edge of the fully loaded sample, and a surface area larger than the surface area of the compressed tire bale. The loading platens were also sufficiently stiff to distribute the load uniformly across the sample in order not to bend or deform during testing.

A minimum of three vertical deformation measurements were made to an accuracy of 2.5 mm (0.1 in.), by gages located within equal distances around the sample (e.g., 3 gages located at the third points around the sample.) Lateral movement was also measured in at least three equally spaced (from top to bottom) vertical locations on all four sides of the sample. A calibrated load cell was used to measure the applied load. Both continuous data monitoring (with data acquisition methods) and manual readings were used to check vertical and horizontal deformation as a minimum at every 45 kN (10 kips) up to 450 kN (100 kips) and at every 112.5 kN (25 kips) up to the full load condition. An unload–reload test was performed on one tire bale.

The stress-strain curves obtained from the tests are shown in Figure 4.2. The test results indicated that the tire bales tested did not have a peak strength at stress levels of less than 815 kPa (17 ksf). The vertical strain of the tire bales was over 60% at the maximum test loads. However, at working stress levels [less than 50 kPa (1 ksf)], strains are much lower and will be further reduced by confinement as discussed in the next section. Circumferential deformation measurements also indicated a relatively low Poisson's ratio on the order of 0.1 to 0.2 at low working stress levels [less than 50 kPa (1 ksf)], increasing to 0.3 to 0.4 at higher stress levels. Lateral movement at low stress levels is likely restricted by the combination of compression during baling, vertical orientation of the tires in the bale and the restraint from the wire ties.



Figure 4.1 Typical tire bale compression test setup

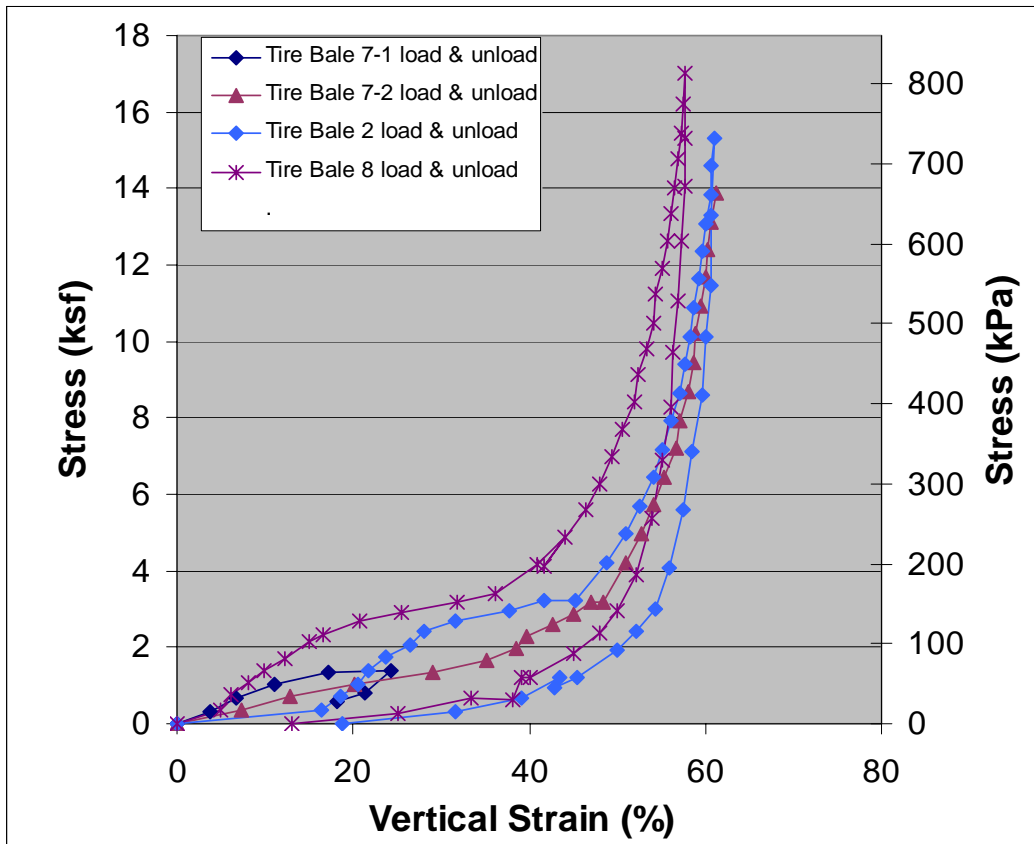


Figure 4.2. Stress-strain results from tire bale compression tests

4.5 Unconfined and confined compressibility tests (i.e., without and with infill materials) at working loads, including static and cyclic modulus evaluation

These tests were performed in a similar manner as the previously described compression tests except that the maximum load was 90 kN (20 kips), e.g. equivalent to a 5.2 m (17 ft) thick tire bale embankment above the sample, and the cyclic load test was performed at 40.5 kN (9 kips) using a 0.3 m (1 ft.) diameter plate to simulate a vehicle load at the surface of the tire bale.

Two tests were performed on two separate tire bale samples, one was performed on the tire bale alone “unconfined” and the other was “confined” by surrounding the bale with a minimum of 0.15 m (6 in.) of dry, fine to medium sand. For the confined test, the sample was placed in a rigid concrete box, the sand was placed in the annulus between the sides of the box and the sample, and the surface of the sand was compacted with a minimum of five passes by a vibratory plate compactor. Surface depressions in the sand that developed during compaction were refilled and compacted to form a level surface prior to applying the test load.

Prior to performing the static compression tests, cyclic load tests were performed. These tests were performed to evaluate deflection under construction traffic and to provide a pseudo evaluation of resilient modulus. The test was developed specifically for this study and is a type of plate bearing test. A rigid circular plate of 1 ft (300 mm) in diameter and a load of 45 kN (9 kip) applied at a 1 ± 0.5 hertz frequency was used to simulate traffic loading (i.e., a standard single wheel load moving at construction speeds). A level bearing surface was provided beneath the circular plate using a non-shrink mortar mix. The test was performed for a minimum of 1000 cycles. Vertical deformation measurements (to an accuracy of 0.0254 mm (0.001 in.) were made using LVDT's and a data acquisition system.

The cyclic load test results for the unconfined and confined tire bales are shown in Figure 4.3. The minimum deformation represents permanent deformation in the tire bale and appears to be fairly similar for the unconfined and confined conditions. However the peak deformation is significantly reduced for the confined case and correspondingly the peak deformation minus the minimum deformation, representing a resilient value, is correspondingly reduced.

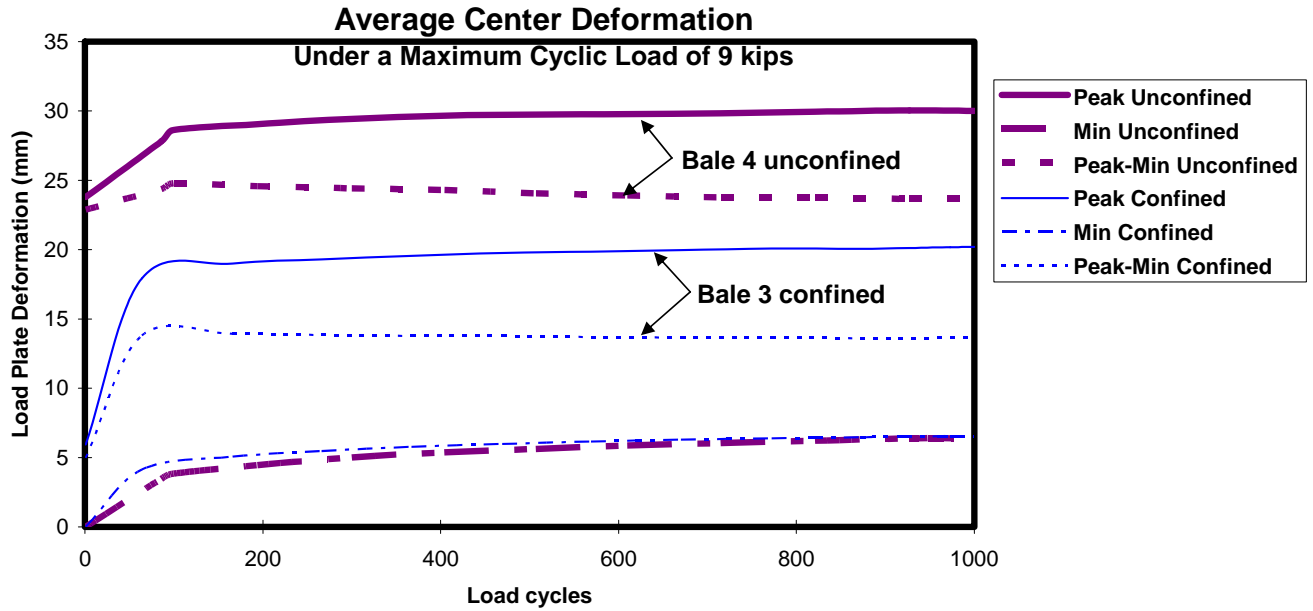


Figure 4.3. Confined and unconfined cyclic load test results

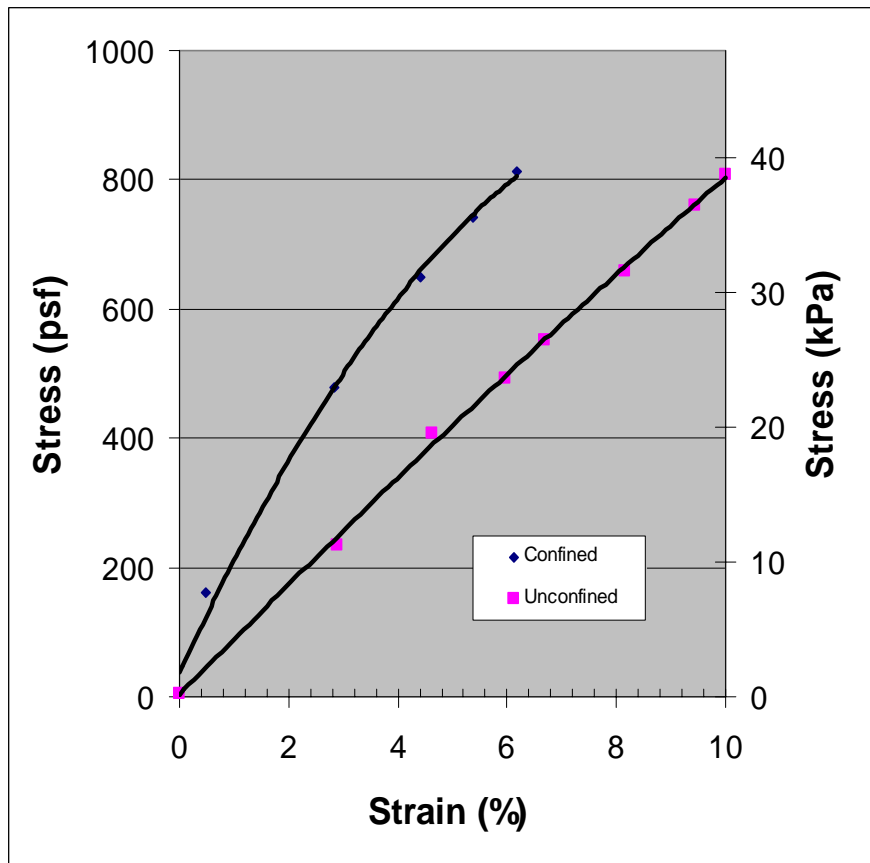


Figure 4.4. Unconfined and confined stress-strain characteristics of tire bales

The resilient value corresponds to a modulus of subgrade reaction of approximately 21 MN/m^3 (77 pci) for the unconfined case and 41 MN/m^3 (150 pci) for the confined case. An equivalent resilient modulus value would be on the order of 21 MPa (3 ksi) unconfined and 52 MPa (7.5 ksi) confined, which even unconfined is over twice that of tire sheds and equal to that of EPS.

Following the cyclic load test, a static load deformation test was performed to 95 kN (20 kips). The stress-strain results obtained from the unconfined and confined tests are shown in Figure 4.4. The curves in Figure 4.4 clearly show that the modulus of the system is improved with confinement of the tire bale, indicating a benefit of infilling. Even when infill is not used, some confinement will be provided by the surrounding bales, indicating that strains under working stress conditions (i.e., settlement of a pavement surface due to tires in embankment) will be low (on the order of 6 to 10 %), most of which should occur during construction. Settlement of the pavement surface could be further controlled by preloading (e.g., overbuild the embankment by approximately 10%), as is currently done for tire shreds (with 20% overbuild typically required).

4.6 Time-Dependent deformation of tire bales under sustained load (i.e. creep)

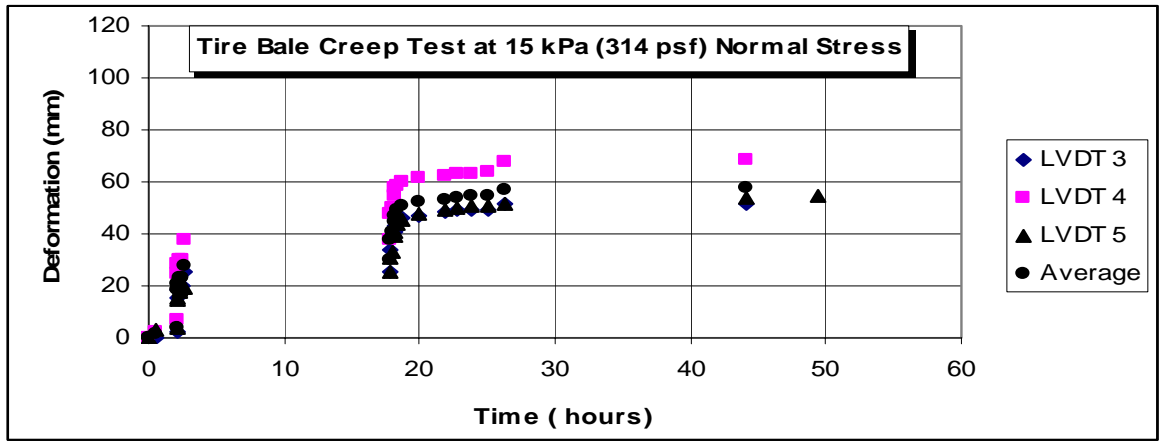
The tire bale creep tests consisted of placing a constant load on a single, “fresh” (i.e., previously not used) unconfined tire bale and monitoring the deformation response for a period of up to 1,000 hrs (1.39 months) at a constant room temperature. The test setup is shown in Figure 4.5. As shown in the figure, the tire bale was placed on the base of a concrete box, which provided the reaction. A 25 mm (1 in.) thick steel plate with an area greater than the compressed tire bale was placed over the bale as a load platen. Twin air bags were used to sustain the required load. A second steel plate was placed above the air bags, and a load cell was placed between the upper steel plate and a reaction beam to monitor the applied stress. The vertical deformation measurements were made using three gages, with an accuracy of 0.0254 mm (0.001 in.) placed evenly (at the third points) around the sample. Three tests were performed. One tire bale was tested with an applied load of 36 kN (8 kips), equivalent to a vertical stress of 15 kPa (314 psf) based on the cross sectional area of the bale, for a period of 60 hours. This stress simulates a normal cover thickness over the bales [i.e., 0.6 to 1 m (2 to 3 ft) of cover soil]. The other two tests were loaded to 90 kN (20 kips), equivalent to a vertical stress of 39 kPa (815 psf),



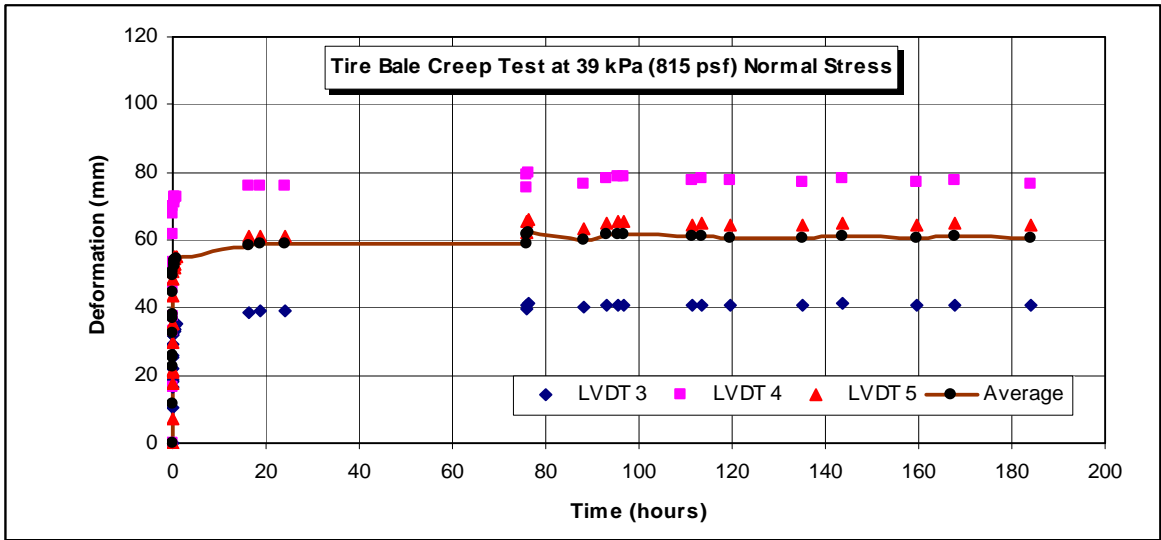
Figure 4.5. Creep test setup.

simulating the stress on the bottom bale of a 5.5 m (18 ft) thick embankment including 1 m (3 ft) of soil cover. The first 90 kN (20 kips) test experienced accelerated movement on one corner after approximately 190 hours and the test had to be terminated. There is a tendency for tires to shift laterally in their unconfined condition. This problem was also noted in the compression testing, but should not occur when tires are confined by other tires (as well as infill, if used). The second test was performed for a period of 1000 hours.

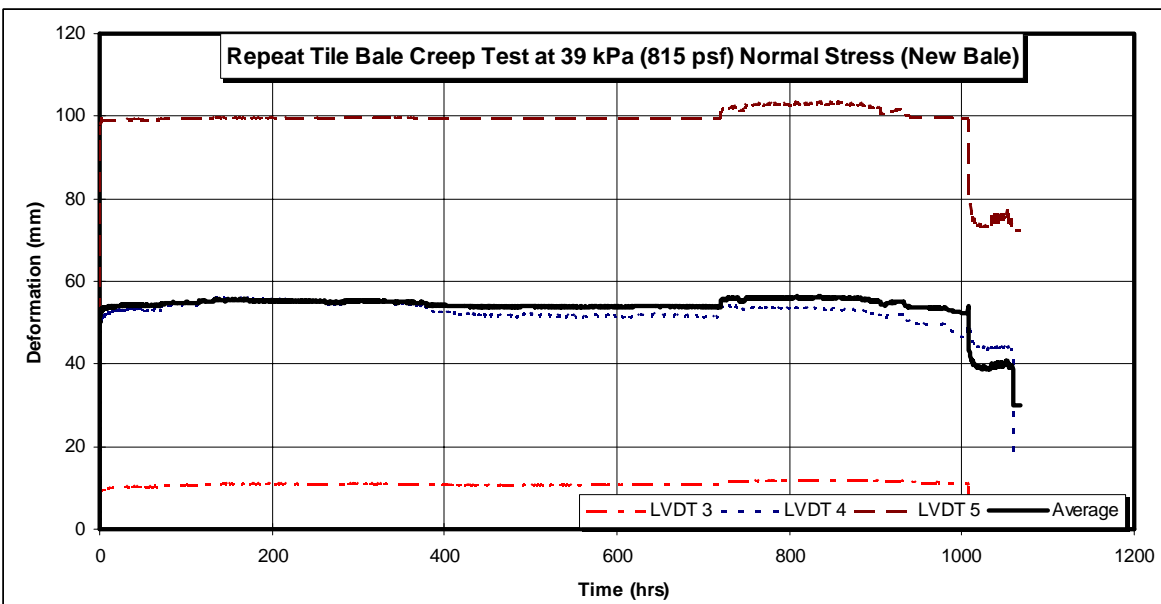
Creep curves for all tests are shown in Figure 4.6 and indicate relatively little creep response at low, working stress levels. Approximately 95 % of the deformation occurred in the first day and the maximum deformation appeared to occur within three days. Progressive deformation in different regions of the bale resulted in variation in both deformation and load, making the determination of creep strain rate difficult. However, the creep deformation did not exceed 1.5 mm (0.06 in.) on average over the last 900 hours of sustained loading resulting in an estimated creep strain rate of 0.005 %/day. This post 3-day movement would roughly be the anticipated post construction movement and, as previously indicated, could be reduced by preloading.



A)



B)



C)

Figure 4.6. Creep test results showing: a) 15 kPa (314 psf) normal stress test, b) 39 kPa (815 psf) normal stress test, and c) repeat 39 kPa (815 psf) normal stress test

4.7 Shear strength of interface between two vertically stacked tire bales

In this test, a direct shear test of the tire bale interface was performed by: 1) vertically stacking two tire bales, with the tire treads in each tire bale oriented in the same direction; 2) restraining the upper bale from moving laterally; and, 3) measuring the force required to pull out the bottom tire bale, which was supported by a steel plate moving on low friction rollers. A hydraulic jack and steel frame placed over a steel load platen was used to apply the normal load. Tests were conducted at normal loads of 9 kN (2 kips) (i.e., the dead weight of the upper bale), 18 kN (4 kips), and 27 kN (6 kips). During application of shear force the bales tended to roll due to interlocking at undulations on the interface surfaces, rather than slide along the interface. This resulted in eccentric loading on the load cell used to monitor the normal stress and the test had to be stopped before a peak shear stress could be reached. Figure 4.7 shows the results of the shear tests and represents a lower bound shear envelope due to the loading problem. The interlock is represented in the results by the adhesion intercept (approximately 2.4 kPa (50 psf)) and a lower bound interface friction angle δ ranging from 25° to 30°.

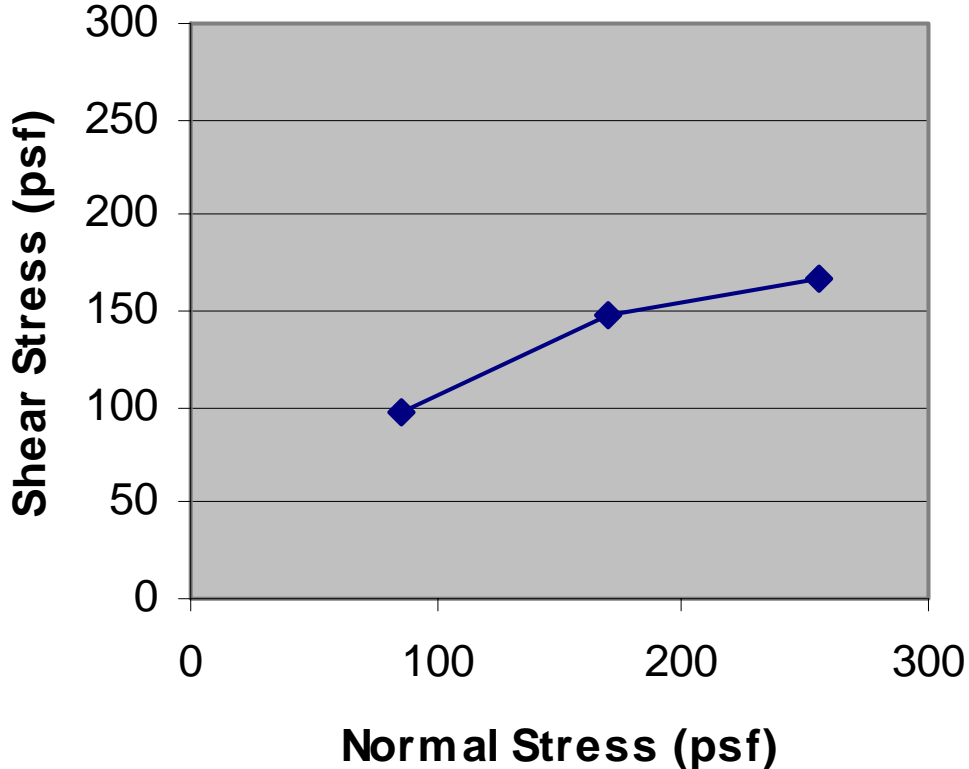


Figure 4.7. Shear at interface between two vertically stacked tire bales (1 psf = 48 Pa)

4.8 Rebound of tire bales and potential expansive pressure of tire bales

Tests were performed to investigate the long-term performance of tire bales (before the end of service life) when there is a possibility that tie wires around the tire bales could break, allowing the tire bales to swell. Wire breakage would primarily be of concern for the upper level bales and bales near the sides where vertical and lateral earth pressures are low. In order to evaluate the uplift potential of tire bales, two tests were performed, one to evaluate free swell and the other to evaluate swell pressure. In the first test, a rigid piston with a load cell was placed on the sample using a wooden pallet as a platen to facilitate cutting of the wires. The five vertical tie wires were then cut and the load required to prevent any upward vertical movement was measured. The load to prevent uplift was relatively small and stabilized within an hour at 1.6 kN (360 lbs), which is equivalent to a normal stress of only 0.70 kPa (14 psf). However, after cutting of the wires, significant lateral movement was observed and continued after the load had stabilized. After no increase in upward pressure was observed, the load was released and the upward vertical movement was monitored until no additional movement occurred. A relatively small average vertical movement of 25 mm (1 in.) was measured. The lateral movement was significant with almost 600 mm (2 ft) of movement observed in the band width direction [300 mm (1 ft) on each side], until the bale was restrained by the sides of the 2 m wide (6.6 ft) container as shown in Figure 4.8.

Due to the significant lateral movement observed during the first test, the second test was performed by restraining the lateral movement with several lifting straps, simulating confinement by adjacent tire bales. All five vertical tie wires on a tire bale were cut and the upward vertical movement monitored. The vertical movement appeared to stabilize within the first few hours at approximately 36 mm (1.4 in). Monitoring continued for a period of 4 days with no additional movement observed. These results indicate that the band width direction, which is the direction of compression loading during fabrication, is the most critical direction in terms of swelling movements and pressures. The bales used in the test were manufactured at different times. However, due to differences in test setup, no observations could be made concerning age of the bales. In future rebound tests, aging should be evaluated and an effort should be made to evaluate the stress required to laterally constrain the bales (i.e., prevent lateral movement).



Figure 4.8. Rebound test on tire bales showing lateral expansion in the first test

4.9 Summary of measured tire bale properties

Table 4.1 lists physical and mechanical properties that will likely be required to develop design and construction practices for tire bale embankment systems. The data is taken from the laboratory tests in Appendices C and F, information cited by tire baler manufacturers, and literature reviewed for this report.

Table 4.1 Physical and mechanical properties of tire bales.

PROPERTY	VALUE	COMMENTS
UNIT WEIGHT		
--Unconfined, dry	5.2 to 6.1 kN/m ³ (33 to 39 pcf)	See Appendix D. Agrees with typical values cited by tire bale producers.
--Unconfined, wet	5.8 to 6.4 kN/m ³ (37 to 41 pcf)	See Appendix D
--Unconfined, submerged	0.5 to 0.9 kN/m ³ (3 to 6 pcf)	See Appendix D
--Insitu with soil	7.8 to 9.4 kN/m ³ (50 to 60 pcf)	Estimated by authors assuming 0.15 m (0.5 ft) of soil in void between tires + 0.76 m (2.5 ft) of tire bale in each 0.91 m (3 ft.) layer & no soil in bales.
--Encased with concrete	11 kN/m ³ (70 pcf)	For ¾ size tire bale, 1.2 m ³ (1.56 yd ³) & a total weight of 15 kN (3.4 kips) (Urro Block by Northern Tyre ,2004)
SPECIFIC GRAVITY	1.01 to 1.2	Range of values for bulk, saturated surface dry, and “apparent conditions” for tire shreds having steel or glass belts (ASTM D 6270).
HYDRAULIC CONDUCTIVITY		
--Unconfined Intrinsic	0.05 to 0.1 cm/sec	Depends on head. See Appendix D
--Unconfined Bale layer	unknown	Anticipated: Relatively high, depends on opening size between tire bales.
--In situ with soil infill	≥ tire bale intrinsic value	Depends on soil type used to fill opening between tire bales.
COMPRESSIVE STRENGTH		
(March 2000 Test) Load to 1,507 kN (339 kip)		See March 2000 Test Data - Appendix C Test Bale ~ 30 in. x 50 in. x 60 in.
• Maximum Applied Stress	773 kPa (16.28 ksf)	Load Deflection Test (LDT) used 50 in by 60 in. (20.8 ft ²) steel plate.
• Strain at Maximum Stress	54 %	Sample preloaded by Creep Test (see below) before performing LDT. Strain based on 11.5 in deflection at maximum load and H (after creep) of 22 in.
Reload Modulus (Initial Tangent)	831 kPa (17.5 ksf)	After Creep Test, initial modulus in LDT computed at 150 kip & 9 in. deflection (i.e., strain = 41 %.)

Table 4.1 Physical and mechanical properties of tire bales (continued)

PROPERTY	VALUE	COMMENTS
COMPRESSIVE STRENGTH (2004 Test Data) background Loads up to 2670 kN (600 kip) <ul style="list-style-type: none"> • Maximum Applied Stress • Strain at Maximum Stress • Modulus (Initial Tangent) 	<p align="center">815 kPa (17 ksf)</p> <p align="center">57.7 %</p> <p align="center">400 kPa (8.3 ksf)</p>	<p>See 2004 Test Data in Appendix D and Figure 4.2.</p> <p>Stress based on corrected area of loaded tire bale.</p> <p>Strain based on initial bale height</p>
Confined Modulus (Initial Tangent)	<p align="center">960 kPa (20.0 ksf)</p>	<p>See Appendix D</p>
CREEP TEST		
Load to (390 kN (88 kip)) <ul style="list-style-type: none"> • Applied Stress • Settlement --Immediate (within 1st hr) --Short-term (72 hrs.) Creep Rate (at 72 hrs) 	<p align="center">202 kPa (4.2 ksf)</p> <p align="center">183 mm (7.22 in)</p> <p align="center">204 mm(8.06 in.)</p> <p align="center">4.6 mm/day (0.18 in./day)</p>	<p>See March 2000 Test Data in Appendix C</p> <p>24 % strain, based on Ho = 30 in.</p> <p>26.7 % strain</p> <p>0.6 % strain/day</p>
Working Stress Tests (89 kN (20 kip)) <ul style="list-style-type: none"> • Applied Stress • Settlement --Immediate (within 1st hr) --Short-term (72 hr) --Long-term (at 1000 hr) • Creep Rates --Short-term (72 hr) --Long-term (at 1000 hr) 	<p align="center">39 kPa (0.82 ksf)</p> <p align="center">51 mm (2 in)</p> <p align="center">54.5 mm(2.1 in.)</p> <p align="center">56 mm (2.2 in.)</p> <p align="center">1.0 mm/day (0.04 in./day)</p> <p align="center">0.04 mm/day (0.0015 in./day)</p>	<p>See 2004 Test Data in Appendix D</p> <p>Stress based on corrected area of loaded tire bale and strain based on initial bale height</p>
Lateral Earth Pressure Insitu: Ko, Ka, Kp	<p align="center">To be evaluated</p>	<p>Function of applied stress and confinement</p>

Table 4.1 Physical and mechanical properties of tire bales (continued)

PROPERTY	VALUE	COMMENTS
Poisson Ratio <ul style="list-style-type: none"> • Working Stress (\cong10 to 30 kPa) • High Stress levels 	<p align="center">0.1 to 0.2 0.3 to 0.4</p>	<p align="center">See Appendix D</p>
Interface (Between Bales) Shear Strength	<p align="center">$\delta \geq 25^\circ$ and $a = 2.4 \text{ kPa}$ (50 psf)</p>	<p>Lower bound value. Function of applied stress and confinement – See Appendix D</p>
Rebound due to breakage of tie wires <ul style="list-style-type: none"> • Free vertical movement • Uplift pressure 	<p align="center">36 mm (1.4 in.) 0.7 kPa (14.5 psf)</p>	<p>Note only 1 or 2 wires failed under max. compressive stress. Long-term tie wire durability is a function of installation damage and environment.</p> <p>Laterally restrained Unconfined</p>
Thermal Properties		
<ul style="list-style-type: none"> • Thermal Conductivity, k_{bale} W/m-°C (Btu/hr-ft-°F) • Thermal Resistance, R (°F-ft²-hr)/(Btu-in) • Exothermic Reaction – Flammability 	<p align="center">0.15 to 0.21 (0.085 to 0.120)</p> <p align="center">0.98</p> <p align="center">To be evaluated</p>	<p>Based on theoretical k of whole tires = 0.128 (Shock et al., 2001) and 50 to 10 % air in tire bales.</p> <p>Based on 1/k per inch of material and 50% air in tire bale from lab test (App.F).</p> <p>Function of size of tire materials, cleanliness, exposed steel, moisture, air, thickness of tire materials.</p>
Chemical Durability	<p align="center">High</p>	<p>Tires are affected by ozone.</p> <p>Aging mechanism principally oxidation accelerated by heat. In air and sunlight, embrittlement of tires starts in about 5 years with notably degradation in 10 years (e.g., sidewall cracks in tires). In soil, common chemicals apparently do not affect rubber tires and the influence of ozone and oxygen are minimized. Tires, still in good condition, have been excavated from 50 year old landfills.</p>

4.10 Material properties of tire bales and other lightweight fills

There are a number of lightweight fill alternatives available for embankment and slope construction. Table 4.2 provides a list of lightweight materials along with their respective unit weight and relative cost for comparison with tire bales. The table verifies the relative low-cost of tire bale materials as compared to other lightweight fill alternatives.

Table 4.3 provides a comparison of the typical design properties considered pertinent for use of a hypothetical tire bale embankment, tire shreds in embankments, expanded polystyrene (EPS) blocks, with a conventional earth embankment. This comparison focuses on the use of tire bales and conventional materials that would typically be utilized for general embankment and slope repair applications. The numerical values were obtained from literature reviews and interviews conducted for this report.

The comparison clearly indicates that EPS provides the lightest weight and is thus the preferred material where very lightweight fill is required. However, in many applications, the 60 to 70 % weight reduction over soil provided by tire bales would be more than adequate to provide embankment stability and/or reduce settlement to tolerable levels. In applications where other characteristics such as permeability, compressive strength, resilient modulus and cost are important, tire bales would appear to provide superior characteristics over tire sheds and EPS. As previously indicated, the ability for tire bales to sink also offers an advantage in applications where floating and uplift of EPS blocks would be of concern.

Table 4.2 Summary of various lightweight fill materials (from Stark, et al., 2002)

Lightweight Fill Type	Range in Unit Weight, kN/m³ (lbf/ft³)	Range in Specific Gravity	Approximate Cost \$/m³ (\$/yd³)	Source of Costs*
EPS (expanded polystyrene) block geofoam	0.12 to 0.31 (0.75 to 2.0)	0.01 to 0.03	35.00 – 65.00 (26.76 – 49.70)	Supplier
Foamed Portland- cement concrete geofoam	3.3 to 7.6 (21 to 48)	0.3 to 0.8	65.00 – 95.00 (49.70 – 72.63) (3)	Supplier (16)
Wood Fiber	5.4 to 9.4 (34 to 60)	0.6 to 1.0	12.00 – 20.00 (9.17 – 15.29) (1)	(17)
Shredded tires	5.9 to 8.8 (38 to 56)	0.6 to 0.9	20.00 – 30.00 (15.29 – 22.94) (1)	(18)
Expanded shale and clay	5.9 to 10.2 (38 to 65)	0.6 to 1.0	40.00 – 55.00 (30.28 – 42.05) (2)	Supplier (16)
Boiler slag	9.8 to 17.2 (62 to 109)	1.0 to 1.8	3.00 – 4.00 (2.29 – 3.06) (2)	Supplier
Air cooled blast furnace slag	10.8 to 14.7 (69 to 94)	1.1 to 1.5	7.50 – 9.00 (5.73 – 6.88) (2)	Supplier
Expanded blast furnace slag	Not Provided	Not Provided	15.00 -20.00 (11.47 – 15.29) (2)	Supplier
Fly ash	11 to 14.1 (70 to 90)	1.1 to 1.4	15 – 21.00 (11.47 – 16.06) (2)	Supplier
<p>Cost Notes: These prices correspond to projects completed in 1993 to 1994. Current costs may differ due to inflation.</p> <p>(1) Price includes transportation cost.</p> <p>(2) FOB at the manufacturing site. Transportation costs should be added to this price.</p> <p>(3) Mixed at job site using pumps to inject foaming agents into concrete grout mix.</p> <p>* Baker, et al., (2003) indicates that common borrow for earth embankment in Washington generally ranges from \$5.25 to 7.85 /m³ (\$4. to 6 /cy) and lightweight fill materials have the following unit prices:</p> <ul style="list-style-type: none"> • Tire shreds, in place \$18.30 /m³ (\$14/cy) • Wood Fiber \$5.88 to 26.16 /m³ (\$4.50 to 20 /cy) • EPS-Geofoam \$78.50 /m³ (\$60 /cy) • Foam Concrete \$72 to 104 /m³ (\$55 to 80 /cy) 				
<p>Reference Notes: (13), (16), (17) and (18) refer to references in Stark, 2002.</p>				

Table 4.3 Comparison of typical reported properties of tire bales, tire shreds, EPS blocks, and earth fill materials.

Property – (Units)	Tire Bale (No ASTM Tests)		Tire Shreds (ASTM D6270)		EPS BLOCKS (ASTM D6817)		Earth Fill (ASTM / AASHTO / DOT Tests)	
	Reported Values	Remark	Reported Values	Remarks & ASTM Test Methods	Reported Values	Remarks	Reported Values	Remarks
Dimensional Tolerances	+/- 5%	Based on lab test App. F confirm for different balers	Specification	Measure D 422	+/- 0.5 % of theoretical	Cut to spec (3)	NA	
Shape Tolerances	Unknown	Rounded corners very rough faces	Specification	Measure	Manufactured	Cut to specification	NA	
Unit Weight kN/m ³ (pcf) --Dry	5.2 – 6.3 (33 – 40)	Lab test App. F *Compute % soil	3.3 to 6.8 (21 to 43) (dry, no soil)	Lab test, loose to compacted ASTM D1557	0.1 – 0.5 (0.7 to 3)	ASTM C578 (3)	15 to 22 (100 to 140)	Lab test
--Wet (Long-term)	5.8 to 6.4 (37 to 41)				1.0 (6.4)			
Specific Gravity	1.02 to 1.2	Not critical	1.02 to 1.27	Lab test, C 127	0.01 to 0.03		2.5 to 2.7	Lab test
Water Adsorption (%)	2 to 9.5	~ Same as Tire Shreds – 8% in lab test App. F	2 to 9.5	Lab test, C 127	2 to 4	ASTM C272	Varies	
Permeability (cm/sec)	0.05 to 0.1	Lab test App. F	0.8 to 59	Without soil matrix	Relatively impermeable		10 ⁻⁶ to 10 ⁺²	Lab Test
Compressive Behavior -- Ultimate Strength kPa (ksf)	> 815 (17)	Lab test App. F Function of fabrication	480 (10)	Maximum reported from lab test	at 10% strain = 40 to 690 (0.8 to 14.4)	Function of density, stress, strain, time, temperature(3)	100 to 1000 (2 to 20)	Lab Test
--Elastic Limit kPa (psi)	NA	Lab test App. F indicate strain hardening	NA		15 to 280 (2.2 to 40.6)	Value at 1% recommended for design (3)	Variable	Lab test

Property – (Units)	Tire Bale (No ASTM Tests)		Tire Shreds (ASTM D6270)		EPS BLOCKS (ASTM D6817)		Earth Fill (ASTM / AASHTO / DOT Tests)	
	Reported Values	Remark	Reported Values	Remarks & ASTM Test Methods	Reported Values	Remarks	Reported Values	Remarks
-- Vertical Strain (%) ---- Ultimate	60	Lab test App. F	50	Varies with vertical stress & time (2)	50	*Design value (3)	5 to 20%	Lab test
---- At Working Stress	2 to 10	10 to 40 kPa (210 to 840 psf)	10 to 25	10 to 40 kPa (210 to 840 psf)	1* to 10		1 to 5%	
--Modulus ----- initial tangent, kPa (ksf)	400 (8.3) 960 (20)	Lab test App. F Unconfined Confined -sand	50 to 250 (1 to 5.2)	Bulk modulus from compression tests	4k to 10k (80 to 210)	based on CBR = 2 (3)	5k to 200k (100 -4,000)	Lab test
----- resilient modulus MPa (ksi)	21 (3) 52 (7.5)	Unconfined Confined - sand	2 to 10 (0.3 to 1.5)	mixed with 30 % sand	21 (3.0)		55 to 275 (8 to 40)	
Poisson's Ratio	0.1 to 0.3	At working stress	0.17 to 0.32	(2)	0.09 to 0.18	In elastic range (3)	0.15 to 0.45	
Earth Pressure - Ko, Ka, Kp	TBD	Test TBD	Ko =0.26 to 0.47 Ka = 0.22 to 0.25	Ko decreases with depth. Part of compression tests, measure in walls (2)	Ko = ? Ka = 0.1 Kp = ?	(3)	0.3 to 0.8	Lab test
Shear Strength kPa (psf) - Internal: in material	TBD	Test TBD	$N = 20^\circ$ to 39° a = 0 to 2.4 (0 to 50)	Dry shreds, varies with normal stress & deformation	Su = 36 (758)	Rare test (3)	$N = 25^\circ$ to 45°	Lab test
- Internal Interface (within embankment) kPa (psf)	$\delta > 25^\circ$ and adhesion a = 2.4 (50)	Bale to bale. Lab test App. F confirm -field test	$\delta = 20^\circ$ to 39° a = 0 to 2.4 (0 to 50)	Dry shreds, varies with normal stress & deformation	30°	Typical (3)	NA	
- External Interface (embankment & adjacent material)	As req'd by design	Bale on soil, geotextile or geomembrane Test - TBD	As req'd by design	Sheds on Soil, geotextile or geomembrane determine by tests	10° to 55°	Varies with materials (3) determine by tests	NA	Lab test

Property – (Units)	Tire Bale (No ASTM Tests)		Tire Shreds (ASTM D6270)		EPS BLOCKS (ASTM D6817)		Earth Fill (ASTM / AASHTO / DOT Tests)	
	Reported Values	Remark	Reported Values	Remarks & ASTM Test Methods	Reported Values	Remarks	Reported Values	Remarks
Connection Strength	As req'd by design	Field Test TBD	NA		Mechanical by barbed steel plates	26° Pseudo – cohesion (3)	NA	
Thermal Conductivity, k (effective) W/m-°C (Btu/hr-ft-°F)	0.15 to 0.21 (0.085 to 0.120)	Theoretical based on whole tire and 50 to 10 % air in tire bales	0.16 - 0.32 dry (0.09 to 0.18)	Varies with size & density of shreds (back calculated in 1998 at NETC field test section) (3)	~ 0.02	(3)	~ 0.17 to 0.7 (0.1 to 0.4)	Lab test, typical soils (2 & 5)
-- Thermal Resistance, R (°F-ft²-hr)/(Btu-in)	~ 1.0	Based on 50% air per lab test App. F	~ 0.8		~ 4.5		0.5	
Exothermic Reaction & Flammability	Control by design guides and storage procedures	Protect exposed tires	Concern in stockpiles and exposed materials	Control by design guidelines, specification, use soil separation layers (2)	Flame retardant by ASTM C578	Blowing agent has ignited. Use flame retardant (3)	NA	
Leachability	TBD	Same as, or less than tire shreds	Ba, Cd, Cr, Hg, Pb, & Se are below regulated amount.	TCLP data D 6270, (Fe, Mn, & Zn also noted in some tests)	NA	(3)	NA	Except for contam- inated materials

NOTES: NA = not applicable, TBD =to be determined,
(1) “Normal chemicals used in current environment do not attack whole synthetic rubber tires,”
personal communication with M. Blumenthal Rubber Manufacturers Association, 7 Oct 2003.
(2) Humphrey, 1998
(3) Stark et al., 2002
(4) Baker, 2003
(5) Oosterbaan, 1963

5. TIRE BALES IN TRANSPORTATION APPLICATIONS

5.1 Introduction

As was shown in Table 2.1, there are a number of potential civil engineering applications for tire bales. Several case histories of general civil applications including use in erosion control features and in the construction of an earth dam are included in Appendix A.

With regard to transportation applications, tire bales are a promising product that can be used for stabilization purposes (e.g. similar to a stabilizing effect provided by thick gravel layers or geosynthetic reinforcements). The lightweight of tire bales allows them to serve as a fill while reducing the driving force and stabilizing a slope that would otherwise experience potential failure. Since the bales weigh less than conventional fill materials, they will induce less settlement of subsurface soils and lower lateral pressure on structures such as walls or abutments. Because of their relatively high hydraulic conductivity, they allow for good drainage. In addition, the bales are easily handled with a wheeled or tracked forklift (or a light hydraulic crane lift). The use of small equipment for placement combined with the elimination of conventional fill requirements for moisture control, ballast, and compaction makes construction with tire bales easy and relatively fast. The environmental benefits of using these waste materials rather than disposing of them is undeniable. Finally, the cost of using tire bales in civil engineering applications is less than that of conventional fill materials. In short, tire bales offer both environmental and economic benefits.

Transportation related applications include, but are not limited to: roadway sub-grade fill, repair of failed slopes, improving slope stability, embankments for roadway structures, backfill material for retaining walls, frost heave mitigation, sound barrier walls, and rockfall barriers. Case histories for a failed slope remediation project and two roadway embankment projects are included in Appendix B.

Based on the review and assessment conducted in this study, a prioritized list of highway applications involving the use of tire bales is presented next. This list provides the Colorado Department of Transportation (CDOT) with an assessment of research needs to enhance the use of tire bales in future projects. The list of highway applications includes use of tire bales as:

- Embankment material within embankment systems.
- Embankment mechanical stabilizing elements in slope repair projects.
- Impact elements and fill material in rockfall barriers.
- Core material for constructing sound walls.
- Embankment on soft ground subgrades and enhanced lateral drainage.
- Shoulder protection of small retaining walls and abutments.
- Backfill material in retaining structure projects.
- Mechanical stabilizing elements in low, less critical retaining walls.

Based on discussions with the CDOT, the first three of these applications were determined to be readily implementable and there are a significant number of projects in Colorado where tire bale structures could be used. We understand that the fourth application, sound barriers, is already being evaluated by others within the CDOT.

The remainder of this section is focused on the use of tire bales in the first three transportation applications, namely: Embankment Construction; Slope Repairs, and Rockfall Barriers. All three applications involve placement of fabricated tire bales, using appropriate connections and anchors, filling void space (if required) and surrounding the assembled tire bales with appropriate matrix materials suited for each application. Each application is discussed separately, using Section 5.2 General Embankment Construction as a “basic construction element” and then discussing the other two applications in Section 5.3 Slope Repairs and Section 5.4 Rockfall Barriers. Each section notes the issues and items which should be considered, or not considered as the case may be, in addition to Section 5.2 General Embankment Construction.

5.2 General embankment construction

General: The total thickness of tire bales in embankment construction has typically been considered as less than 6 m (20 ft), utilizing one to perhaps eight layers of tire bales placed on a graded subgrade. The subgrade below the bottom tire bale layer normally includes compacted native soils. Some site conditions might require localized placement of a compacted free-draining granular base zone or compacted tire shreds. Tire bales are typically placed in “brick fashion” with the

0.75 m (30 in) dimension vertical and each layer is staggered to offset vertical joints on overlapping layers. This arrangement helps to maximize the interface friction between the bales and effectively minimizing any differential movement. Tire bales may be connected, depending on site requirements. In some cases soil has been placed and compacted between successive layers and against the sides of in-place tire bales to isolate individual tire bales. Alternately, the tire bale/soil zone could be encapsulated with a flowable fill, or encapsulated with a high strength geotextile separator, to reduce soil and moisture penetrations into void space in a tire bale. The use of a geotextile separator is considered simpler to construct and more cost effective (as will be discussed in Section 7).

Application: The generic tire bale embankment system typically involves 0.75 m (2.5 ft) thick layers of tire bales in conjunction with other materials, as shown in Figure 5.2, to provide specific benefits that can be tailored to a range of site conditions. The benefits can include:

- An economical embankment.
- Subgrade enhancement, that can insulate, drain, and strengthen.
- Stabilization of soft subgrades to provide a working platform, possibly incorporating a geosynthetic reinforcement/separation at the base, in order to construct an embankment.
- Engineered lightweight fill, to reduce settlement of soft foundation soils, and provide increased shear strength for global and sliding stability reasons.
- Reinforced zones, consisting of tire bales alone, or improved by placing geosynthetic reinforcement between bales, that provide relatively high internal shear strength to facilitate construction of steep slopes and near vertical headwalls.
- Erosion control from surface flow, channelized flow, or wave action at the edges of lagoons, ponds, and lakes.

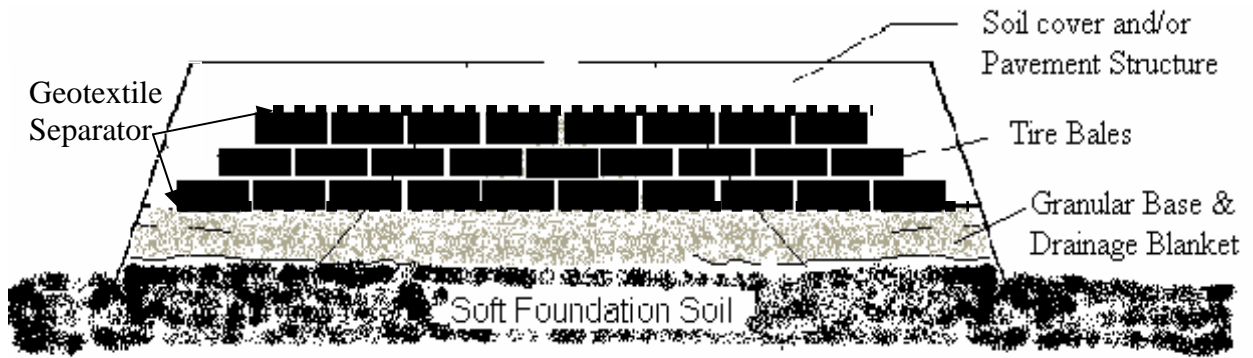


Figure 5.1 Application of tire bales in embankment construction.

5.3 General slope repair and stability improvement system

General: The generic tire bale embankment zone is placed in an excavated area after soil and/or rock slide debris are removed as shown in Figure 5.2. Depending on the site conditions, the excavation may require temporary earth support systems and the use of groundwater control measures to facilitate construction of slope repairs.

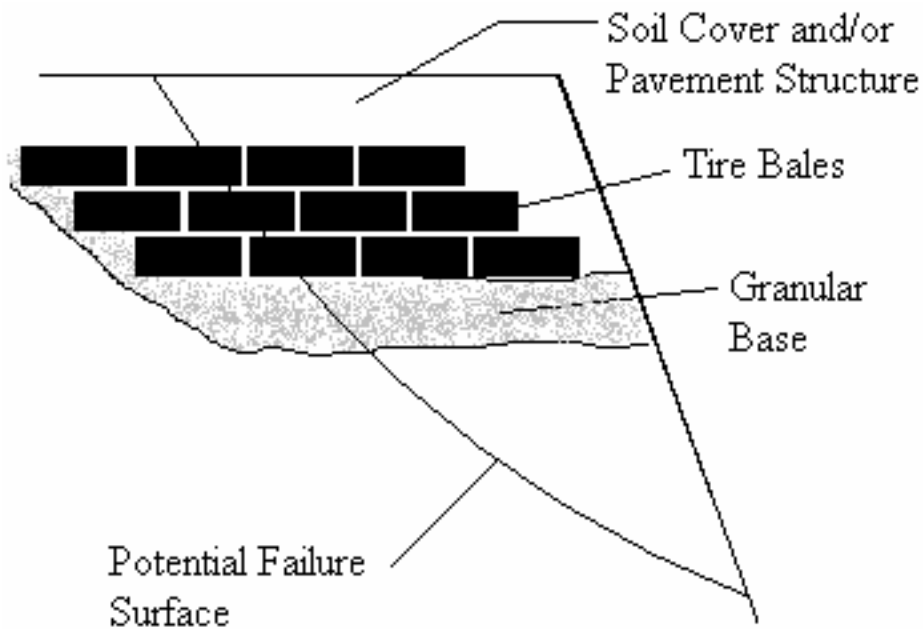


Figure 5.2 Tire Bales Used to Improve Slope Stability

The thickness, face slope, back slope and face angle for the tire bale embankment depends on the site conditions and the use of stability analysis of various cross-sections to provide an adequate Factor of Safety (Fs) for the remedial construction. Crushed stone and/or geosynthetic drainage systems will likely be required along the base and along some portion of the backslope of the tire bale embankment. Geotextile separation layers may be required to prevent movement of adjacent soils into the voids in and between the tire bales.

Development of a stacking and placement pattern to maximize interlocking of the tire bales, including the possible inclusion of soil or crushed stone separation layers and geosynthetic reinforcement materials in conjunction with mechanical connection devices, may be a significant aspect of the design and construction work. For this application the design will focus on the benefits of: (1) the lightweight tire bale fill to decrease the driving force, and (2) the potentially high internal and interface shear strength of the tire bales to develop an integrated reinforced tire bale embankment zone with reliable shear strength properties.

The subgrade layer could consist of a compacted free-draining granular base zone, compacted tire shreds, or compacted native soils. Site conditions may also require installation of drainage systems to control groundwater movement as well as consideration of small to large size drainage pipes exiting through the face or below the toe of the face slope. The available foundation area will directly impact the design face angle and the selection of facing materials.

In some situations a stepped face, covered with soil and a vegetated surface, or an unvegetated rock fill, may be acceptable to the owner. It is also conceivable that in other situations the tire bale face could be “stepped” to provide a steep, very steep, or vertical face covered with shotcrete or metal, concrete, and treated timber panels. The panels could be fabricated, formed, and colored to provide an aesthetically pleasing surface that blends with the natural topography and vegetation that would be environmentally acceptable as natural habitat for animals, birds, etc.

Application: A typical Tire Bale Slope Repair or Stability Improvement System can provide:

- An engineered lightweight fill, with a high strength embankment fill volume.
- Internal drainage.
- Shear strength to satisfy global and sliding stability factor of safety requirements.
- Support for an acceptable face system.
- Connection strength for soil/rock anchors extending behind the excavation.
- Erosion control from surface flow, channelized flow, or at the edges of lagoons, ponds, and lakes.

5.4 General rockfall barrier walls

General: The generic tire bale rockfall barrier wall is usually placed between a roadway and a steep rock face, either as a free-standing wall unit, or as the “impact face” of a geosynthetic reinforced soil (GRS) wall (as was shown in Figure 2.1), to prevent falling rock materials from impacting roadway traffic. Depending on site conditions, the offset from the highway, the height and thickness of the barrier wall and the appropriate use of other rockfall control devices (such as cables and wire mesh) would be integrated with the tire bales.

For either the stand alone wall, or a GRS wall system, the width, depth, and possible use of shear keys below a foundation pad, will also depend on the design for the size and velocity of a critical rock block and the modulus of the tire bale system. Pylons, earth/rock anchors, or tire bale buttress elements may be required to provide stability and/or additional impact resistance for the free standing system.

For the stand alone wall, the use of crushed stone and/or geosynthetic drainage systems is not anticipated as a typical design issue. Development of an interlocking stacking and placement pattern to maximize the benefits of tire bale interlock, inclusion of geosynthetic reinforcement materials to a modular block face wall with the tire bale section, and inclusion of connection devices, may be a

significant aspect of the design and construction work. The angle of the outside “design face” is expected to be near vertical. We anticipate that the “impact face” (back side) would not have a facing material in order to cushion and stop falling rocks. The exterior of the road side face could be a modular dry laid block, shotcreted, or stepped at varying face angles with a soil/vegetation cover, and/or covered with a placed stone/rock cover for aesthetic reasons, as was discussed in the slope repair application section. Fire protection issues for the impact face should be examined.

For the GRS system, tire bales would generally be laid parallel to the roadway, stacked to stagger and cover the underlying joints, and could include tire bales placed perpendicular to the roadway to enhance interlocking behavior. Figure 5.3 shows a stacked tire bale arrangement similar to that of the impact face of the rockfall barrier. Geosynthetic reinforcement would be placed between each layer relying on friction between the modular block face wall and the geosynthetic reinforcement to provide the face connection. The vertical spacing would be at every bale, i.e., 0.75 m (2.5 ft) vertical spacing. The geosynthetic reinforcement would extend to the outside (road side) wall face where either modular block or wrapped face with shotcrete construction could be used. The roadside face of the wall may also require short secondary reinforcements for improved face stability. Design and construction would follow standard CDOT GRS design guidelines.



Figure 5.3. Stacked tire bales, e.g., to form the impact face of a rockfall barrier (Encore Systems, 2004)

For the stand alone wall application, the design may also include the use of soil/rock vertical anchors to resist lateral impact loadings from roadway traffic and/or rockfall materials. The design should also consider the low unit weight of the tire bale fill, and utilize the internal shear strength and interlock strength of the tire bales, with connection/anchor devices to develop an integrated reinforced tire bale rock barrier wall zone with reliable strength properties.

The subgrade layer for either system could consist of a compacted free-draining granular base zone, compacted tire shreds, or compacted native soils. Specific site conditions may require installation of drainage systems to control groundwater movement and consideration of small to large size drainage pipes exiting through the face or below the toe of the face slope.

Application: A typical Tire Bale Rockfall Barrier Wall System can provide:

- An engineered high strength wall system to resist the impact of falling soil/rock debris and control the bounce and roll of the debris.
- Adequate shear and connection strength to satisfy desired Factor of Safety (Fs) for overturning, global, and sliding stability failure modes.
- Support for an acceptable outside face system, and other materials such as cables and wire mesh.
- Connection strength for soil/rock anchors extending below or behind the foundation zone.
- Erosion control from surface flow, channelized flow adjacent to the barrier wall structure.

6 DESIGN GUIDELINES FOR TIRE BALE EMBANKMENTS

6.1 General

Complete design guidelines have not yet been developed for use of tire bales in embankment applications. However, as previously indicated, ASTM has prepared a general guideline specification for use of tire shreds (ASTM D6270), which addresses some issues relevant to proposed design guidelines for tire bales. FHWA has prepared “User Guidelines for Waste and By-Product Materials in Pavement Construction,” which includes a section on use of scrap tires as embankment fill. However, the FHWA document does not cover design issues specifically related to tire bales. In addition, FHWA has design guidelines for embankments over soft subgrades (FHWA HI-95-038), which would apply to the use of tire bales as fill and could accordingly be modified to form a basis for design. At this time there is no recognized material specification, laboratory testing procedure, or design practice guideline for tire bale embankments as existing applications have been designed and constructed in piecemeal fashion.

6.2 Lightweight fill systems

The NCHRP Guidelines for Geofam Applications in Embankment Projects, (Stark, et al., 2002), provides design guidelines for EPS block materials and focuses on the use of this lightweight fill material in embankment applications. The report includes state-of-practice design approaches for:

- Support of overlying pavement systems.
- Evaluating internal and global stability of geofam embankments on very soft soil foundations.
- Manufacturing quality control and quality assurance (MQC/MQA) issues.
- Typical design details.
- Economic analyses.
- Topics for future research and development, and
- AASHTO formats for provisional design guidelines and material standards.

This National Cooperative Highway Research Program (NCHRP) guideline report has considerable value because it documents approximately 30 years of the development of design/construction guidelines for use of geofoam materials as a lightweight fill. We believe this guideline along with the existing FHWA and Colorado DOT guidelines provide excellent resources that can be used to assess some of the issues relating to use of tire bales as a reliable engineered material in reinforced and unreinforced highway embankments and wall structures. As indicated in both Table 3.1 and Table 4.3, the properties of tire bales in embankment applications are not well defined or available in the engineering literature. However, the general design issues and approaches relating to use of conventional earth fill, EPS blocks, and tire bales are very similar.

Table 6.1 provides a preliminary comparison of the design issues, assuming that in the future tire bales can be fabricated with an adequate level of MQC/MQA that will provide consistent verifiable quality of manufactured tire bales for confident use as a reliable engineering material. The comments in the table provide the authors' opinion on the relative importance of each design issue for the selected application with status and knowledge of the design issue for tire bales relatively ranked as: "Not Available", "Very Limited", "Limited", and "Satisfactory". The notations of "1", "2", and "3" are intended to indicate a preliminary relative assessment of the importance of a design issue in the design of tire bale systems (1 is high and 3 is low).

6.3 Tire bale specifications

Development of specifications for tire bale fabrication, testing, and construction is a very important issue at this time. The Texas Department of Transportation (TxDOT) has prepared a preliminary draft specification for use of tire bales and associated materials in the repair of a localized slope stability failure of an embankment. Note that this specification has not been finalized and that it would be substantially modified before it is used in a construction contract (Williammee, 2004). This specification is included in this report solely for the reader's information because it does address some of the issues involved with a tire bale construction project. The specification is included in Appendix E (for information only) and summarized below.

Table 6.1 Authors' summary of design issues for tire bale embankments, slope repairs and rockfall barrier applications.

Issue	Status of Knowledge & Understanding	Embankment Construction*	Slope Repairs*	Rockfall Barriers*
I. Reliable Tire Bale Properties				
Material Standard	Not Available	1	1	1
Physical Properties				
Weight	Satisfactory	2	1	1
Dimensions & Tolerances	Very Limited	2	2	1
Flammability	Not Available	1	1	1
Durability / Environmental	Limited	3	3	3
Impact of Baler Design and Operation	Not Available	2	2	1
Mechanical Properties				
Compressive Strength	Limited	2	1	1
Creep & Relaxation	Limited	1	1	1
Tension	Not Available	3	3	1
Flexure	Not Available	3	3	2
Shear Strength:				
Internal & External	Very Limited	2	1	1
Interfaces of tire bales	Very Limited	2	1	1
Interface with Separation Materials	Very Limited	2	1	1
Thermal Properties	Very Limited	3	3	3
II Site Constraints				
TBD –Depends on ranking site issues for each application				
Key items include requirements for: drainage, base separation, infilling, cover layers, and buffer zones.	Very Limited	2	1	1
III. Design Guidelines				
Manufacturer's experience	Limited	2	1	1
Private Consultant Experience	Very Limited	1	1	1
University Research	Very Limited	1	1	1
State DOT's	Very Limited	1	1	1
Federal Highways	Not Available	1	1	1
IV. Tire Bale Specifications				
Private Consultant Experience	Very Limited	1	1	1
University Research	Very Limited	1	1	1
State DOTs	Very Limited	1	1	1
Federal Highways	Not Available	1	1	1
<p><u>Note:</u> * Importance of a design issue to application development with 1 = high, 2 = moderate, and 3 = low.</p>				

6.3.1 Summary of Texas DOT preliminary draft specification

General Requirements. The Texas specification indicates the following:

- Tire bales restricted to auto or light to medium truck scrap tires generated or stored within the State of Texas.
- Tire balers and baling sites shall be authorized to process scrap tires by the Texas Commission of Environmental Quality.
- Obtain approval of plans by engineer and local fire department for fire prevention and suppression two weeks before start of tire bale production and storage.
- Tire bales are specified as Type A.
- Tire bales required to be uniform in shape and size, or "equivalent as approved by engineer" (but measure not specified) and density $> 5.6 \text{ kN/m}^3$ (35 pcf.).
- Bale ties shall be galvanized or stainless wires, with maximum break stress of 345 kPa (50 psi). (Corrosion protection of ties as required by Item 423.2 should be followed. However, this protection is not required when bales are covered by a geomembrane which makes a tire fill impermeable to air and water and not subject to pH and resistivity requirements.) Requires that tire bales shall not explode when wires are cut/broken.
- Tire bales used as core of embankment.

Laboratory testing. The specified laboratory tests of tire bales include:

- Compression test equipment uses 25 mm (1 in.) inch thick steel plates top and bottom, approved test floor, I-beam to distribute load, max 1,777 kN (400 Kip) load capacity hydraulic ram.
- Creep test for 72 hrs, test at 172 kPa (25 psi = 3.6 ksf).
- Max creep strain < 0.25 or 190 mm (7.5 in.) for a 762 mm (30 in.) high tire bale.
- On same bale do load test to failure, or to maximum of 690 kPa (100 psi = 14.4 ksf).
(Note: failure load, failure stress, and failure strain are not defined)

Design and construction. These requirements for tire bale embankments include:

- Prepare subgrade, operate parallel to final road grades.
- Maximum tire bale height = 6.56 m (20 ft.), and is the core of the structure.
- Place granular base below tire bales, 300 mm (12 in.) thick, extended to allow drainage.

- Construct embankment to minimize air and water infiltration.
- Place bales with straps in longitudinal direction of roadway.
- Place and compact soil between each layer of tire bales, 200 mm (8 in.) thickness, soil PI<35, 300 mm (12 in.) maximum loose thickness, provide moisture control, and proof roll if required by the Engineer.
- Organics not allowed and soil to be checked by color test.
- Geomembrane is placed over final layer.
- Soil placed on side slopes, minimum of 450 mm (18 in.), then 50 mm to 100 mm (2 to 4 in.) thick layer of compost.

6.3.2 Comments on the Texas DOT draft tire bale specification

The specification requires creep tests at loads of approximately 2.5 times the maximum service stress at the bottom of the bales with a maximum stress of 690 kN/m² (100 psi). This is equivalent to total load of approximately 1450 kN (325 kips) on a 1.4 m by 1.5 m (4.5 ft by 5 ft) tire bale. The test is intended to fail the material in unconfined compression. For reference, the creep test load, e.g. 2.5 times maximum service stress, for an embankment section composed of 1 m (3.3 ft) of soil and 6.1 m (20 ft) of tire bales would be approximately 150 kN/m² (3 ksf)

The authors suggest the following additional laboratory tests:

- Measure and evaluate the rebound movement and the lateral bulge of the tire bale during both loading and rebound.
- Creep tests should be conducted at 0.5, 1.0 and 1.5 times maximum service stress at the bottom of the tire bale embankment in order to evaluate estimated settlement of the upper portions of the tire bale embankment during construction and the amount of over build required (using tire shreds, tire bales, or soil buffer materials) to develop and maintain design grades for the top of the tire bale embankment, and/or develop preload/surcharge requirements to reduce most construction creep settlements. The creep period may extend beyond 72 hours for some design conditions.
- rebound movement (vertical heave) on confined or restrained tire bales along with lateral pressure exerted by tire bales on the restraints should be evaluated when tie wires are cut.

The authors believe the draft Texas DOT specification provides a good starting point for developing a comprehensive tire bale specification and also suggest that some of the items in the draft specification may not be needed for all tire bale embankments. Specifically the use of intermediate soil layers between each tire bale layer and the requirement for a geomembrane cover or wrapping may not be required (or desirable) in many applications. The intermediate soil cover appears to be related to the exothermic issue and is more stringent than required for tire sheds in ASTM D 6270. As indicated in Section 3, the exothermic problem does not appear to be as significant for tire bales as it does for tire sheds; and, for tire shed projects, intermediate cover is only required for embankments greater than 3 m (10 ft or approximately 4 bales) in height. Although not included in the specifications, geotextiles should be required between the cover soils and the tire bales unless infill is used between the bales. The geomembrane requirement is apparently related to the exclusion of water and air to reduce both the exothermic problem and the potential long-term corrosion of tie wires. As noted in the specifications, by reducing air and water, the pH and resistivity requirements for intermediate covers and infill are reduced. If infilling is not used then the pH and resistivity of adjacent fill are less of a concern. As discussed later in this section, tire bales are not expected to produce a leachate that is as severe as tire sheds. However, until further studies have been performed on the leaching potential of tire bales and to prevent contamination from residual materials that may be left in the tires, a geomembrane cover should be used where the embankment will be located near a water supply or when placed at or below groundwater (as would also be recommended for tire sheds).

In comparison to the draft Texas DOT specification, the structure and content of the ASTM D6270 Guidelines for tire shreds and the “Guidelines for Geofoam Applications in Embankment Projects” (Stark et al., 2002) are very detailed and inclusive for the respective materials given the time those processed materials have been used in a variety of civil engineering applications. ASTM D6270 documents the body of knowledge developed over the past 14 years by extensive testing of typical tire shred materials and the design guidelines developed in 1997 address the issues involved with reducing exothermic heating reaction in tire shred fills. ASTM D6270 includes a Material Data Sheet (MSD) for whole scrap tires. The Guidelines for Geofoam Applications...” are very comprehensive and detailed, covering EPS material properties developed over approximately 50 years and the design approaches that have evolved since

extruded polystyrene insulation layers were first tested in highway pavements in the United States in 1960s and expanded polystyrene blocks (EPS) were first used as a lightweight highway fill material in the early 1970s in Norway.” (Stark et al., 2002).

The proposed Colorado DOT tire bale specification should address the following issues:

- Reference documents, including terminology, and laboratory test procedures.
- The responsibilities of the parties involved with the fabrication, storage, transport, and installation of a tire bale embankment system.
- Permitting requirements for waste tire storage, transport, including pre-processing, cleaning, storing, etc.
- Equipment and procedures for fabricating tire bales, including confinement devices.
- Physical, material, and chemical properties and requirements for MQC testing, possibly including third-party testing and certifications to verify the tire bales have the requisite properties before they are transported to storage or to a construction site.
- Product storage and transportation with fire protection and fire suppression requirements.
- Site preparation, including placement of ancillary foundation materials.
- Handling and placement of tire bales, ancillary materials, and any connection devices.
- Requirements for handling and installing facing materials.
- Field quality control monitoring and testing tire bales and ancillary materials.
- Performance monitoring, both short-term (from placement to the end of construction) and in-service monitoring. Appropriate instrumentation to monitor and measure settlement, lateral movement, temperature, and water head may be required at some sites to verify the tire bale embankment is performing as anticipated during design.

Table 6.1 lists the current understanding of some of the tire bale properties and their relative importance for the selected applications. In order to establish preliminary pre-design test values and increase the amount of available background, an effort should be made on each project to pretest tire bales for relevant properties. It is also important to note that laboratory test values are sometime different from observed in-service behavior (Humphrey, 1998 and Baker et al., 2003)

The critical properties include:

- Compressive stress-strain properties for different types of tire bales (function of fabrication stresses, tire type, and resulting density) for unconfined and in situ confined conditions.
- Internal shear strength, lateral sliding resistance for tire bale interfaces, as a function of stacking, geometry, and interlocking arrangement.
- External sliding resistance in conjunction with proposed abutting and interlay materials, including soil, stone, concrete, geotextiles, geogrids, or geocomposite drains.
- Short-term and long-term creep behavior for a range of design loads.
- Lateral and vertical expansion characteristics, assuming tie systems may break after construction.

Developing this information requires the construction, instrumentation, and monitoring a full scale test embankment where the tire bale system can be subjected to typical design loadings and appropriate instrumentation is installed to enable comparison of laboratory test data to in-service performance.

6.4 Tire bale fabrication

Current typical tire bale dimensions have developed from commercially available tire bale equipment to compress approximately 100 auto size tires to produce a 1.5 cubic meter (2 cubic yard) tire bale weighing approximately 8.9 kN (2,000 lb = 1 ton). However, there is no recognized national or international standard for the number of tires, tire bale dimensions, and weight of a tire bale. The number of tires included in the bale can vary with the compaction pressure, the type of tire, and modification of whole scrap tires by pre-splitting. Tire bale dimensions are based on the baler, but there is no baler standard. In addition to the “nominal standard”, ½ size and ¾ size bales have been reported by several producers, especially for tire bales encased with concrete. The smaller sizes for concrete encased tire bales may be related to a perceived limitation that an 8.9 kN (2,000 lb) weight per unit is a relative maximum for transportation and site handling activities.

The number of tires in a tire bale and the tire bale dimensions should be consistently controlled to provide uniformity and consistency in tire bale properties and size for structural design and

installation requirements. Requirements for “surface planeness”, deviation from the nominal size of the baler chamber, and tire bale “squareness” should be included in the dimensional requirements to provide uniformity and facilitate stacking several layers of tire bales and result in relatively level top surface, and reduces void space between adjacent tire bales. Reducing void spaces between tire bales will also reduce the amount of soil filling required, if that feature is required on certain projects. These requirements are also necessary to define and control the anticipated total bulk in-place unit weight and volume of the tire bale zone and the ancillary soil materials that may be used for infill, buffer, and side slope filling.

Measurement of tire bale properties, including geometry, unit weight, permeability, and cleanliness should be responsibility of the tire bale fabricator. The fabricator should provide a statement or certification that the tire bale product conforms to the project specifications, including conformance with state legislation for reuse of waste tires. (See reference to state laws, and the summary of Colorado regulations included in Appendix F).

6.5 Construction sequence

6.5.1 Pre-construction

The first construction activity should be the verification that the tire bales fabricated and selected for the project conform to the project specifications. This may involve use of a third-party testing agency to certify that the tire bale producer’s MQC/MQA materials and fabrication procedures are satisfactory and conform to the project requirements. Conformance tests should also be conducted at this stage, if required by the design engineer/and the third-party testing agency, preferably prior to shipping tire bales to the construction site.

6.5.2 Field operations

The construction sequence for tire bale embankment applications should not be significantly different than those presently used for any other embankment project and will thus include:

- Material handling (e.g., unloading, storage, hauling, placing, etc.).
- Prepare foundation and subgrade.
- Place base drainage (unless it can be shown that drainage is not required).

- Place a bottom geosynthetic separation layer, if required, on the embankment subgrade.
- Place tire bales, and, if required, matrix fill, connections, and reinforcements.
- Place a geosynthetic separation over the tire bale zone, as required.
- Place soil and stone materials required for a buffer zone between the tire bale zone and the pavement system, and side slope fills to support vegetated surface covers, and face protection as required on the sides of the tire bale zone.
- Monitor performance.

Use of a “standard 100 pte tire bale” is attractive from a constructability standpoint, because that size and weight can conveniently handled by conventional forklift equipment. Field reports have noted that the bales exhibit “good performance” when they are stacked in a “brick-like” fashion. Many applications have simply stacked the bales in a “brick-like” fashion, utilizing no other methods for joining the bales. In some of these cases, the stacked bales were used for roadway subgrade, where the bales are exposed, and they have shown good short- and long-term performance. Specifically, it appears that time-dependent movements (creep) have not been monitored, measured, or reported as detrimental.

Even though the tire bales are simply stacked in a “brick-like” fashion for many of the experimental applications, quality control guidelines are needed to ensure short and long-term success of the project. The first layer of bales has been generally placed below ground level. That is, the first layer has served as a “keyed” layer, which “locks” the entire bale mass into the ground by not allowing lateral movement along the base of the lowest layer of tire bales.

Also, depending on the type of project, the bales can be linked together by pre-installing a pipe through the bale and running aircraft cable through the pipe to connect multiple bales. When the bales are stacked together, a 50 to 125 mm (2 in. to 5 in.) variation in surface height may be typical on the top, sides, and bottom of a tire bale. Tire bales should be placed as close together as possible.

When a geosynthetic separation layer is not used in the design, control of soil infills or other materials between bales will be very important to avoid subsidence after placement. Typically, the infill material has been a clean coarse to fine sand, and the estimated cost in Colorado to

install this material could range from \$19 to \$59 / m³ (\$15 to \$45 / cy) (See Appendix H) with a average cost of \$28.50 /m³ (\$22.00 /cy) for moderate size projects. A flowable cementatous fill (i.e. flowable fill) could also be a viable alternative to sand in some situations. Other infill materials should be explored with respect to ease of construction and void filling reliability.

It is the authors' opinion that filling the voids in the horizontal and vertical interfaces between each tire bale is not required for all projects. However, at this time, the need for soil infilling should be addressed by the design engineer, based on the conditions at each site and the availability of geosynthetic separation materials. The recommended alternative to soil in filling is the use of a geotextile separation layer above the tire bale fill zone. This approach is often used for separating rock and boulder fills from fine grained soils. The geotextile will need to be selected based sufficient durability to survive construction, which is anticipated to require, as a minimum, a Class I geotextile as defined by AASHTO M288.

The minimum buffer zone required above a tire bale fill zone also requires further evaluation and will be application dependent. For example, for a soil embankment fill over Expanded Polystyrene (EPS) blocks, a minimum thickness of 0.5 m (20 in.) is required between the roadway subbase layer and the EPS blocks (Stark et al., 2002). Humphrey recommends a thickness of 0.6 to 1.8 m (2 to 6 ft) of adequately compacted soil cap over a tire shred fill (Baker, 2003). Considering the nonuniform surface of tire bales, a minimum of 1 m (3.3 ft) of additional fill should be required between the top of the tire bales and the bottom of the pavement base course where roads are to be constructed over tire bales. If thinner cover is used an FWD test should be performed on the inplace cover material to determine the design requirements for the pavement.

The project contractor should be responsible for transportation, site storage, and installation of the tire bales. The installation phase should include site survey for layout, geometric limits of the tire bales, integration with other materials, and environmental protection until the Owner accepts the project.

The design engineer, or another responsible qualified agency retained to provide construction testing and monitoring services, should monitor the installation of the tire bales and develop as-built drawings and a summary construction report to document the tire bale installation.

Following construction, periodic site visits and measurements should be made to monitor the geometry, appearance, and performance of the tire bale embankment systems.

6.5.3 Monitoring field activities

The design engineer should be available to provide the following services during construction:

- Review adequacy instrumentation design verification monitoring program (e.g., temperature and settlement during construction and in-service) including types of instruments, calibration and installation procedures.
- Review daily field activity and QC/QA reports prepared by the Owner's representative.
- Periodic site visits to verify the field conditions are consistent with design conditions.
- Develop changes to the design plans and specifications as justified by site conditions, review the as-built drawings and the final construction report prepared by the contractor and the testing agency. The final construction report should include all quality control data, field reports, data obtained by survey and instrument readings, and an interpretation of the data.

7 ESTIMATED COSTS FOR TIRE BALE EMBANKMENTS

7.1 Colorado rebates and reported cost savings

As in any other transportation application, cost is an important aspect in the selection of tire bales as a design alternative. While varying from project to project, the cost of tire bales as embankment material has been reported to be less than the conventional soil alternative. In fact, the cost for materials, shipping, and handling tire bales could be offset by the Colorado Division of Local Government and Counties which provides a \$20 per ton (~\$10/cy) rebate for end users or processors of scrap tires. This is due to state legislation and tipping fee subsidies.

An example of the costs and savings associated with the use of waste tires in Western New York state is provided in Case Study 2 in Appendix B. On that project the total taxpayer savings was estimated as \$1.60 per tire, or approximately \$160 for a “standard tire bale” (~\$80/cy). This corresponds to the difference between the normal disposal cost of tires and the cost associated with the use of tire bales (Figure 7.1). The cost savings associated with tire bales instead of conventional earthwork material in Case Study 2 was reported as \$3,050 per 300 m (1000 ft) of roadbed (Figure 7.2). (Chautauqua County, 2001). A summary of Chautauqua County’s experience on four consecutive projects from 1999 to 2002 is included in Appendix B.

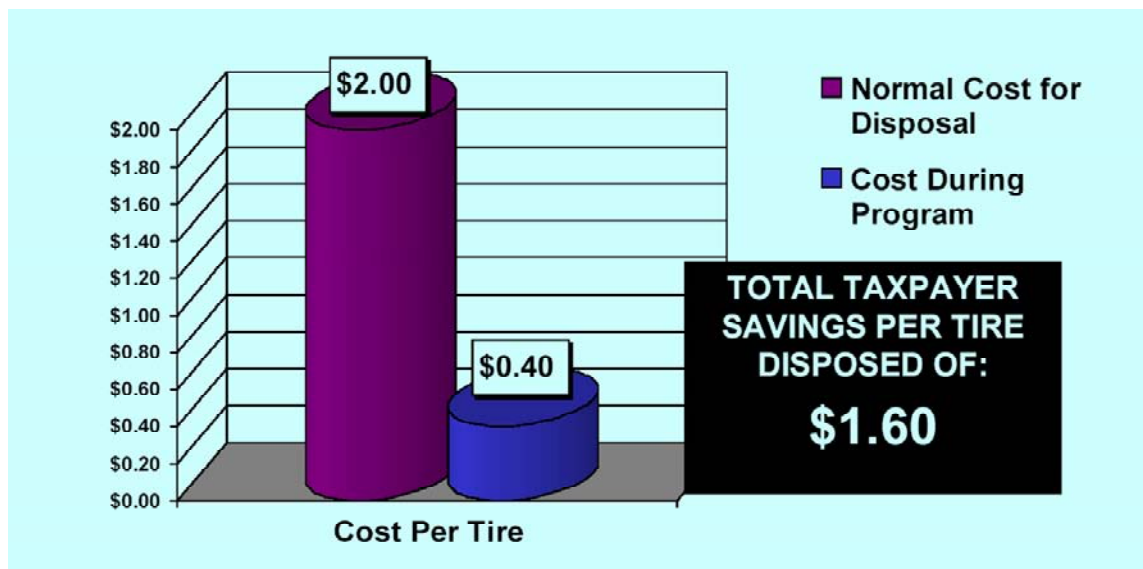


Figure 7.1 Total taxpayer disposal costs for each tire

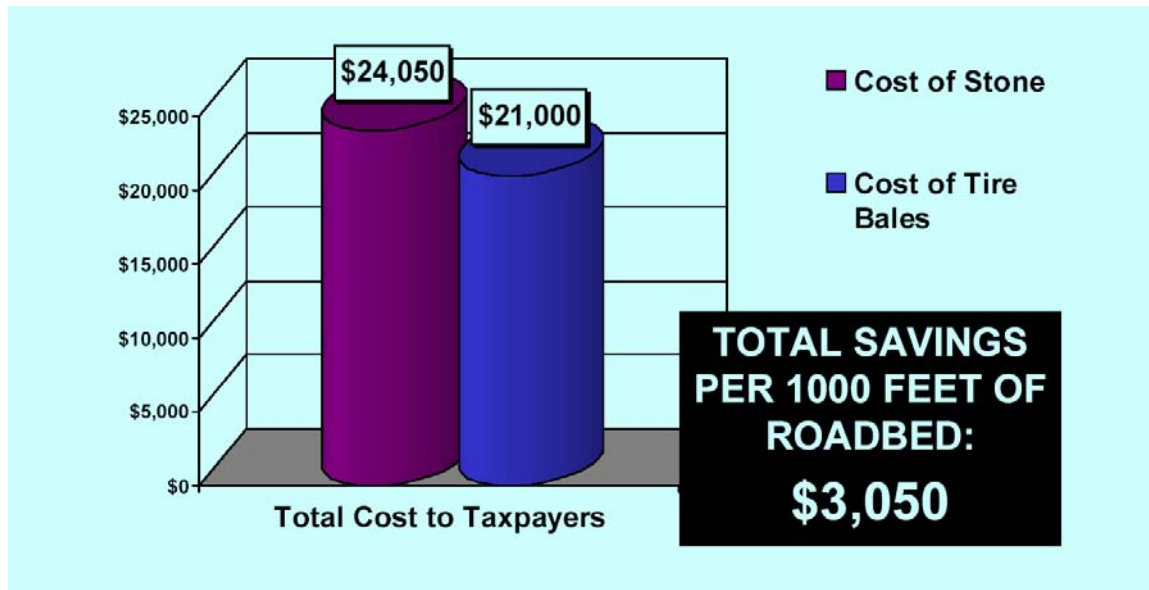


Figure 7.2 Total savings per 1000 feet of roadbed

7.2 Estimated cost of a tire bale embankment in Colorado

Table 7.1 provides a tabulation of the estimated costs to procure, fabricate, transport, and install typical tire bales in a generic transportation embankment. For this example the volume of tire bales required for support of a two-line highway was computed for a tire bale zone with dimensions of 16 m (52 ft.) wide, 0.75 m to 6 m (2.5 to 20 ft.) thick, and 1H:1V side slopes, covered by a separation geotextile and a 1 m (3.2 ft) earth/stone cover below the pavement base course. The cost of the pavement and soil cover on the side slopes is not included in this estimate.

The comment column, notes, and references cited in this table provide background information on the rationale for each cost item. The Colorado DOT provided average annual contract costs for earthwork, geotextile, and filter materials for the 2001 to 2003 time period. This data is listed in Table H.1 in Appendix H.

The comparative replacement cost for using tire bales as a substitute for embankment backfill in Colorado is listed below in Table 7.2. It should be noted that with respect to the average annual cost of embankment backfill for the 2001 to 2003 time

Table 7.1 Estimated base cost of tire bale embankments in Colorado

Item or Activity	Estimated Costs - $\$/m^3$ ($\$/cy$)		Comments (Note 1)
	Range	Base Estimate	
1. Material Cost of Scrap Tires	0	0	A tipping fee pays for current disposal of waste tires.
2. Fabricate, Handle, Store	13.08 to 15.67 (10 to 12)	14.39 (11.00)	Includes wire ties. (Note 2)
3. Transport to Site	2.49 to 4.71 (1.90 to 3.60)	3.27 (2.50)	Estimate: 25 miles @ \$5.50/ton = \$2.50/cy [varies to 100 miles @ \$10/ton = \$5.00/cy]
4. Store, protect, handle tire bales at site	0.65 to 1.31 (0.50 to 1.00)	0.78 (0.5)	Assume \$0.50 / cy
5. Class A Geotextile above Tire Bales	0.52 to 1.05 (0.40 to 0.80)	0.78 (0.60)	(Note 3)
6. Total 1 to 5	16.74 to 22.76 (12.80 to 17.40)	19.10 (14.60)	Estimate Base Cost to Fabricate, Deliver, and Install
7. Less Colorado Rebate	13.08 (10.00)	13.08 (10.00)	(Note 4)
8. Estimated Net Cost	3.66 to 9.67 (2.80 to 7.40)	6.02 (4.60)	(Note 5)

NOTES

1. Assume approximately 100 tpe and $1.5 m^3$ / bale, (2 cy /bale = 1 ton / bale). CDOT unit costs for 2001 to 2003 are listed in Appendix H, Table H-1.
2. Assume: Crew & equipment costs \$100/hr and production rate is 4 to 5 bales per hour, (8 to 10 cy/hour). Then unit cost is \$10 to \$12/cy.
3. Assume: Tire bale zone is 3 m (10 ft) thick, total volume = $30 m^3$ (23 cy) / LF of roadway, geotextile covers $8.3 m^2$ (10 sy) / LF of roadway, and geotextile costs \$2.40 / m^2 (\$ 2.00/sy).
4. \$20/ton rebate to end user or scrap tire processor = \$20/bale = \$10/cy.
(R. Welle, personal communication)
5. Does not include engineering services, special design details, construction monitoring, etc. Actual cost depends on site conditions and time required to prepare design plans and specifications and monitor construction.

Table 7.2 Estimated cost of tire bales for embankment construction

Item or Activity	Estimated Costs - \$/m ³ (\$/cy)		Comments (Note) (Note 1)
	Range	Base Cost Estimate	
1. Average Project Cost for Embankment Backfill	8.13 to 18.75 (6.22 to 14.34)	12.61 (9.64)	(Note 2)
2. Estimated Net Cost (Item 8 in Table 7.1)	3.66 to 9.67 (2.80 to 7.40)	6.02 (4.60)	
3. Savings by use of Tire Bales instead of CDOT Embankment Backfill	4.47 to 9.08 (3.42 to 6.94)	6.59 (5.04)	(Note 3)
<p>Notes</p> <p>1. Assume approximately 100 tpe and 1.5 m³ / bale , (2 cy /bale = 1 ton / bale). CDOT unit costs for 2001 to 2003 are listed in Appendix H, (\$10.00 /cy = \$13.08 /m³.)</p> <p>2. CDOT average of 2001 to 2003 annual costs for 50.6 % of the 125 projects, (only project volumes from 2,500 to 50,000 cy) range from \$6.22 /cy to \$14.34 /cy and average \$9.64 /cy.</p> <p>3. Estimated net savings are in the order of \$185,000 for a 48,000 cy replacement of Embankment Backfill. A 48,000 cy replacement would relate to a 10 ft thick tire bale zone, 60 ft. wide for 2,150 ft.</p>			

period, the annual cost varies with the size of the project. The unit cost in item 1 of Table 7.2 is based on the average value for 50 percent of the projects where project volume ranged from 3,270 to 65,400 m³ (2,500 to 50,000 cy) in that time period. The reported range of average cost vs. project volume is tabulated in Appendix H.

When significant quantities of tire bales are used in a particular cross-section, the cost of the cover soil in the side slopes areas and the soil buffer between the pavement and the tire bale zone will likely be somewhat larger than the “typical” average value of \$12.61 / m³ (\$9.64 / cy) used in Table 7.2. In addition, the comparative cost of a conventional cross section using embankment backfill must be compared to the cost of all the materials at unit prices appropriate for the material quantity in the alternate backfill / tire bale cross-section. The thickness of the soil buffer layer, the side slope cover volume, the side slope angles, and the type of earth/rock material (if any) used in the side slope covers will likely be the most significant factors that

impact the cost estimate for the alternate cross section. Based on the unit costs for embankment backfill, the unit cost for smaller volumes could be in the range of \$13 to \$20 /m³ (\$10 to \$15/cy) for earthwork quantities less than 6,550 m³ (5,000 cy).

In addition to the estimated costs for alternate cross sections of tire bales and embankment backfill described above, some materials and/or site conditions may require additional efforts or materials. Some of the additional site specific issues that may influence the total cost of the alternate cross-sections are listed in Table 7.3.

Table 7.3 Estimated cost for special material and site requirements

Possible Requirements for Tire Bale Embankments	Estimated Costs - \$/m ³ (\$/cy)		Based on tire bale volume
	Range	Base Estimate	
R-1. Steam clean scrap tires or bales	0 to 10 (0 to 8)	~2 (~2)	(Note 1))
R-2. Devices to connect tire bales	0 to 5 (0 to 4)	~3 (~2.50)	(Note 2)
R-3. Earth Matrix & Infill Material		~8.60 (~6.60)	(Note 3). Does not include intrusion of sand into bales.
R-4 Crushed stone drain below tire bale zone	0.10 to 0.20 (0.80 to 0.16)	~0.14 (~0.11)	(Note 4)
R-5. Face protection	10 to 30 per m ² (1 to 3 per ft ²) of face vertical projection	20 per m ² (2 per ft ²) face vertical projection	Not required for a generic general embankment. Depends on available materials and site requirements.
Notes			
1. Usually not required (R. Welle, personal communication). Perhaps required for contaminated tires or, if tire bales are used on environmentally sensitive projects.			
2. Probably not required for a generic tire bale embankment.			
3. Assume: Earth infill averages 100 mm to 150 mm (4 to 6 in) thick between tire bales. The average unit cost to install clean sand could range from \$15 /cy to \$40/cy for CDOT projects. (Appendix H). At \$28.50 /m ³ (\$22.00 /cy), the soil matrix costs \$8.50 /m ³ (\$6.60 /cy) of tire bale volume.			
4. Assumes: 150 mm (6 in) thickness, 15 m (50 ft) wide of Filter Material Class B crushed aggregate at \$39 / m ³ (\$30/cy). For a drain layer along 10 percent of a roadway and a 3 m (10 ft) thickness of tire bales, the unit cost per cy of tire bale is \$0.15/ m ³ (\$0.11 /cy). bale. Note that actual costs will vary with site conditions.			

7.3 Comparison of estimated cost for lightweight fill

The net cost for fabricating, transporting, and installing tire bales for a typical project is estimated to be in the range of \$3.70 to \$9.70 / m³ (\$2.80 to \$7.40 /cy), averaging \$6.00 / m³ (\$4.60 / cy) depending on fabrication, transportation, storage, and installation costs. These values are at the low end of the 1993 to 1994 range of cost estimates for other lightweight fill materials listed in Table 4.2. The unit costs in that table indicate the following unit cost ranges (excluding handling and engineering):

- EPS blocks: \$35 to \$65/m³ (\$26 to \$50/cy)
- Foamed concrete \$65 to \$95/m³ (\$50 to \$73/cy)
- Fly ash and slag \$ 3 to \$21/m³ (\$2.30 to \$16/cy)
- Shredded tires \$20 to 30/m³ (\$15 to \$23 /cy)

Stark et al., (Appendix A, page 14) by means of a questionnaire obtained a range bid prices from six United States DOTs, including three for the 1996 to 1999 period. The six prices ranged from \$39 to \$98 per m³ (\$30 to \$75 per cy), averaging \$70 per m³ (\$55 per cy). From the authors experience, recent (2000 to 2002) pricing of EPS blocks in special embankment systems has ranged from \$78 to 90 per m³ (\$60 to \$70 per cy) installed in the Mid-Atlantic region of the United States.

7.4 Discussion of other cost issues for tire bale embankments

In addition to the typical ranges of unit prices the Colorado DOT provided for the 2001 to 2003 time period, as tabulated in Appendix H, the comparative cost of a tire bale embankment vs. conventional construction is also affected by other factors involving the project design for specific site conditions, material availability, and contractor bidding practices that should be evaluated on a case by case basis. The significant factors can include:

- Adequate subsidy to offset cost of fabrication.
- Lack of prior experience with design and construction of tire bale embankments.
- Overly conservative design approach, such as soil infill around each tire bale, or implementation of design elements related to tire shred embankments.

- Extensive QA/QC requirements.
- Inclusion of drainage elements.
- Limited supply of tire bales near the project site, and/ or the high cost of tire bale transportation.
- Unbalanced or “opportunity pricing”, instead of Owner supply of tire bales from stock piles at nearby sites, and contractor installation of tire bales on a time and material basis.

A significant consideration for the design and construction of tire bale embankments is the possible requirement to construct a soil zone around each tire bale. This approach has been suggested and implemented on several preliminary tire bale embankments in other states, perhaps based on a conservative perspective that a soil matrix between tire bales, (or other material injected into the interior of a tire bale) is necessary to maximize fire protection and reduce risk of fire propagation, or to decrease deformation of the tire bales during loading. As noted above in Table 7 .3, the use of a clean sand as a soil matrix –only around the tire bale -- can be quite expensive (~\$8.60 /m³ or ~\$6.60 /cy of tire bale volume). This cost is on the order of 10 times the comparable cost of a single layer of Class A separation geotextile between the tire bales and the overlying soil buffer layer, unless suitable materials are available near the site. It is the authors’ opinion at this time that use of a CDOT Class A, or a AASHTO Class I, geotextile should be sufficiently strong to survive construction and thus prevent infiltration of the soil buffer layer into the underlying tire bales.

8 FEASIBILITY, FEATURES, BENEFITS, AND DESIGN/ PERFORMANCE ISSUES

8.1 Feasibility

The assessment of tire bales presented in this report indicates that the use of tire bales in transportation applications is considered feasible. However, some laboratory and field research is required to obtain design parameters, understand some aspects of the insitu service behavior, develop appropriate engineering design procedures, and prepare appropriate contract specifications for use of tire bales in this application. The perceived features, benefits, potential limitations, and field and laboratory research issues are noted in the following sections of this report.

8.2 Features and benefits

With regard to transportation embankment applications, tire bales are considered a promising product that can be used as a relatively low-cost lightweight fill with relatively good mechanical properties. The perceived benefits when tire bales are used as embankment fills are listed below:

- Waste tires are readily available in Colorado.
- Tire bale fills are relatively low-cost, on the order of \$3.70 to \$9.70 /m³ (\$2.80 to \$7.40 cy) (assuming the current Colorado rebate for using scrap tires is in force).
- As a lightweight fill embankment on compressible soils, insitu unit weights in the range of 30 to 50 percent of normal soil fills will induce less settlement.
- Relatively high internal and external shear strength properties, above that of very stiff or dense soil.
- High permeability values, in the clean sand and gravel range, allowing gravity drainage.
- Fabrication of tire bales does not require high quality control requirements, sophisticated molding procedures, and skilled labor.
- Tie bales can be fabricated at convenient locations and stored, with some protection, until they are used.
- Lightweight tire bales, approximately 1 ton units, are easy to transport to construction sites.

- Tire bales can be easily moved and placed by conventional lightweight lifting equipment.
- Colorado Department of Health and Environment does not require permits for use of tire bales in transportation applications.
- Use of scrap tires, presently stockpiled in tire dumps and other waste disposal sites, provides a significant benefit to the state’s environment by using them in beneficial applications.
- Tire bales are generally compatible with other construction materials such as soils, concrete, and geosynthetic materials.
- Tire bale fills are considered to be less likely than tire shred fills to develop exothermic heat reactions, leach manganese and iron, and release organic compounds when placed below a ground water table because much less exposed steel in baled tires.
- Low service creep strains (Lab test on one tire bale indicates less than 0.1 % strain per month with normal stress of 38 kN/m² (800 psf), which is equivalent to a 5.5 m (18 ft) high embankment with an average unit weight of 45 pcf.).
- Tire bales do not expand significantly or “explode” when the wire tires are cut because the fabrication load and “time of restraint” holds the deformed tires together.

8.3 Special considerations, limitations, and research issues

Some of the potential limitations to the use of tire bales in transportation projects are summarized in this section.

- **Fire Protection** A prudent and practical level of fire protection practice should be developed and employed to protect tire bales in storage, in transit, and in an embankment. The required level of protection practices should consider appropriate planning, conformance to fire prevention practices, protection from possible acts of vandalism, localized fire sources, and lightning strikes. The available literature does not provide test reports, or codes, that adequately address the ignitability and flammability of tire bales exposed to a natural (outside) or the soil covered soil environment. Part of the observed practice and practical experience in many states is that a number of large to very large piles, containing more than several million whole scrap tires, have not ignited when exposed to natural (outdoor) conditions for years. However, this experience does not preclude the possibility that a small number of such stockpiles may burn as the result of unexpected fire conditions.

Typical fire codes for whole tires usually address storage and stacking of tires inside buildings. Guidelines for constructing and monitoring stockpiles of tire shreds limit the conditions which can cause exothermic reactions in shredded tire embankments have apparently been successful for projects constructed since 1997. The guidelines require separation of tire shred piles, roads for fire fighting equipment, fencing around the site, and fire marshal approval of storage plans. By extension of the codes and guidelines for the current uses of tire shreds, it appears that storage of tire bales will require similar codes and guidelines.

Compared to tire shreds, the use of tire bales (covered with soil) in embankments should not pose an unusual, or increased fire hazard. Temperature monitoring of the proposed prototype tire bale embankments should provide data that can be compared to temperature buildup in tire shred fills and thus provide additional information on the relative performance of tire bales to tire shred fills with respect to the potential in service fire protection issues.

- **Ground Water Quality.** One concern regarding the use of tire bales and waste tires involves their potential impact on groundwater quality. Although no specific study has been conducted to identify the impact of tire bales on water quality, some studies have been conducted regarding the impact of tire shreds on water quality. For example, an ongoing study sponsored by the Federal Highway Administration involves testing the impact of tire shreds on water quality (organic and inorganic constituents). This study concluded that leachate from the tire shreds does not affect water quality. A summary of the data from the 1990s is included in Humphrey, 1998 and ASTM D 6270.

Section 7.3 of ASTM D 6270 indicates that field studies of tire shred fills above the water table tend to leach Manganese, and under some circumstances, iron at levels above the secondary drinking water standards. Secondary drinking standards refer to aesthetic factors, such as color, odor, and taste – not health concerns. Release of organics from tire shreds above the water table is not considered a significant concern. However, Section 7.4 of ASTM D 6270 indicates that tire shreds below the water table can leach levels of Manganese

and iron that are significantly above secondary drinking standards (aesthetic factors, such as: color, odor, taste – not health concerns). Tire shreds below the water table can leach low levels of a few organic compounds into the groundwater. Section 7.4 indicates “further studies are needed to determine if these levels are high enough to be of concern.” It should be noted that the typical design of tire shred fills usually includes a sealed geomembrane wrap to reduce surface and groundwater infiltrations, as well as base drains to discharge condensation water, in an effort to reduce the free access of air and to keep the tire shred fill in an unsaturated condition and thereby reduce the possibility of exothermic reactions resulting in fires. In addition, a typical design for tire shred fills includes approximately two-foot thick layers of compacted soil to limit the vertical thickness of tire shred fill zones to approximately 8 to 10 feet.

In contrast to tire shred fills, where shred sizes typically range from sand sizes up to approximately 600 mm (24 in.) dimensions, tire bales are usually made with whole tires. Use of whole tires in tire bales is therefore expected to significantly reduce the exposure of steel tire reinforcements and result in a lower level of concern for the possibility of leachate affecting the groundwater environment. (Note, however, that some fabricators do cut truck tires, which exposes part of the steel core, and include them in an “equivalent 100 tire bale”.)

Water flow through permeable tire bale embankments is not expected to produce a leachate with lower quality than that of tire shreds. Considering the leaching potential of tire sheds as reported in ASTM D6270 (as discussed above) and the potential for residual (oils, etc.) materials to remain on tires, it would be prudent to take special precautions at sites located near water supplies or where bales will be placed at or below ground water level. For these applications, CDOT should require that:

- a) tires are cleaned prior to fabrications, and
- b) a geomembrane be incorporated in the design to restrict vertical percolation of water into the tire bale embankment.

Leachate from the tire bale embankments could also be collected and stored in holding basins for periodic analysis of leachate quality prior to site discharge (i.e., if the leachate quality is within Colorado guidelines).

Requirements for conducting leachate tests on typical tire bales, cleaning tires, and/or implementation of geomembrane or other leachate control measures to comply with Colorado water quality requirements, should be part of the design engineer's scope of work.

- **Drainage and Buoyancy.** Concerns have also been raised over the use of tire bales in areas of significant ground water fluctuation and flooding conditions. However, tire bales were reported and confirmed by the laboratory testing performed in conjunction with this study to behave as a “free-draining” unit. That is, water can easily flow through the tire bale. Tire bales were also found to have a submerged unit weight of 0.5 to 0.9 kN/m³ (3 to 6 pcf) and thus should not float due to buoyancy force, which would alleviate concerns in areas subject to flooding. In supporting the laboratory test results, tire bales have been reported to sink to the bottom of a body of water when placed in a lake, river, or pool (Miner, 2003, personal communication). In addition, the in-service condition for a tire bale embankment zone would likely usually include 0.6 m to 2 m (2 ft to 6 ft.) of earth, rock, and pavement materials which would reduce the risk of a buoyant condition.
- **Integrity of Tie Wires and Straps** An additional aspect that deserves further investigation is how the insitu physical and structural integrity of the tire bale, and the tire bale zone, is affected if tie wires or straps deteriorate and rupture during the design service life of the embankment. Observations and experience with handling tire bales with a fork lift, or other mechanical handling devices, indicates that as a minimum, ties are needed to confine the tires after fabrication and during shipment and installation. The need for longer term physical confinement of each bale, involves selection of corrosion protection for metal ties and specification of a long-term strength for all types of ties while the tire bale is in service. Tie design requirements appear to be a controversial issue.

A study reported cutting the wires of tire bales after a set amount of time (e.g. usually one year or more), and observing an unrestrained tire bale. Due to plastic deformation of the bales, the individual tires were reported to not change or expand significantly from the placed geometry. That is, it appears that after a period of time, the tires will not elastically rebound or return their original shape. In fact, it has been observed that less distortion takes place

when the baling wires are cut after long periods of time (Miner, 2003, personal communication). This is an important issue considering that tire bale ties maybe cut during construction or degrade with time. .

Laboratory rebound tests performed as part of this study (see section 4.3.1) confirmed that vertical movement (heave) was minor when tire bales were in either laterally confined or unconfined. Only a small amount of soil cover (less than ½ ft) would be required to prevent any vertical heave should tie wires break. However significant lateral movement did occur in the unconfined test and a significant force was required to restrain the tires in the confined test to prevent such movement. Tire bales could be placed in the embankment with tie wires oriented parallel to the edge of the embankment to avoid failure along the side walls of the embankment. However there could be locations where this is an issue. Nevertheless the lateral stress exerted by tire bales should tie wires break requires further evaluation for designing lateral restrain features (e.g., buttressing berms) where they are required.

Another aspect of this issue is the situation when an excavation must be made into the tire bale fill zone in the future. As excavations are sometimes made in highway embankments for subsurface explorations, install utility poles, utility lines, or to repair or replace existing utility lines. If such an excavation is required, it appears that conventional subsurface explorations drills would not be very effective in penetrating a tire bale fill, but a large backhoe would be able to make a large excavation.

It is the authors' opinion that removal of discrete tire bales, or removal of individual tires from bales after the ties are cut or broken would also be a difficult situation. In order to effectively deal with this situation, accurate as-built drawings will be a very important resource when future excavations or subsurface explorations are conducted. It is also the authors' opinion that replacing the excavated tire bales would not be feasible in small excavations but could be feasible in large excavations. Selection of bedding, backfill, separation materials, and development of construction procedures should be addressed in future tire bale studies.

8.4 Design / performance issues

Table 8.1 provides a list of primary design and performance issues that in the author's opinion should be considered and evaluated in order to implement the three tire bale applications which are the focus of this report.

Table 8.1 Issues related to use of tire bales as embankment fill.

Tire Bale Issues	Short-term	Long-term	Comments
Comprehensive specifications for fabrication of tire bales with consistent properties	Very Important	Very Important	Requires cooperation among the tire balers, bailer manufacturers, and a competitive market for fabricated tire bales
Compression and creep rates, as affected by fabrication variables (compression loads, number of auto tire equivalents, unit weight, and confining bands)	If required, address by preload, surcharge, and monitoring the time to settle and the overbuild thickness required to compensate for short-term compression	Must be confirmed as relatively small for pavement performance reasons; roadway type and traffic loadings should also be considered	Requires laboratory tests and monitoring field test sections
Relaxation or expansion if confining bands break or relax	Possibly repair prior to installation. In place requires monitoring prior to completion of construction.	Important to evaluate, however, may not be an issue based on comments from field projects.	Requires monitoring laboratory tests of tire bales with movable side walls
Interaction with existing and future utilities.	Important for installation of utilities during construction.	Important to evaluate, however, tire bale embankments should be designated as "No Dig Zones"	Requires coordination with utility owners and utility locator systems.
Internal and external shear strength values are function of tire bale interlock, surface asperities, separation materials, and unit weight.	Very Important	Very Important	Requires laboratory tests and monitoring field test sections

Table 8.1 Issues related to use of tire bales as embankment fill (continued)

Fire protection measures	Important during fabrication and storage	Important	Requires additional testing and evaluation
Tire bale permeability	Moderately important	Moderately Important	Tire bales were found to be permeable (see lab test App. F) but requires additional quantification
Requirements for soil buffer layers: a) to support roadways above tire bale embankment b) reduce temperature increase and exothermic reaction in untreated tire bales c) below side slopes, and d) limit thickness of tire bale embankments.	Important Important Important Important	Very Important Important Important Important	Requires monitoring field test sections
Requirements for geotextile separation/filters to minimize soil movement (loss of ground) into internal voids in tire bales.	Very Important	Very Important	Requires monitoring field test sections
Exterior Protection	Not important	Important	Depends on application
Exterior Facing	Important	Important	Depends on application

9 VIABILITY AND FUTURE EFFORTS

Based on the current understanding of the properties of waste tires, as well as on the apparent satisfactory performance of a limited number of embankment projects constructed so far using tire bales, it may be concluded that the use of tire bales as embankment materials is technically and economically feasible and offers significant potential applications in many transportation systems. In addition to the obvious environmental benefit of using recycled waste materials, the lightweight and inherent mechanical strength of tire bales offer advantages over normal fill in terms of reduced stress to the subgrade and improved internal strength of the structure. Based on rebates for recycling scrap tires in Colorado, tire bales are essentially free except for hauling costs. Other normal construction cost for handling and installation should be no greater than conventional embankment construction and the time of construction could possibly be accelerated (especially winter construction).

The current understanding of tire bale feasibility is based on:

1. The quantification of material properties involving the use of waste tires processed as tire shreds, keeping in mind that tire shreds are much different from a tire bale composed of compressed whole tires.
2. Visual inspection of transportation applications that did use tire bales but did not incorporate comprehensive monitoring programs necessary to adequately define long-term performance required for engineered transportation facilities.
3. The results of a companion laboratory testing program to define basic engineering properties of tire bales. (See Section 4.3 and Appendix D of this report).
4. A draft tire bale specification, which outlines many of the design and construction requirements.

Although a significant amount of testing was performed in the companion laboratory test performed as part of this study, the limited amount of test data is not extensive enough to develop reliable statistical relations that adequately describe the variance of the measured properties. It is likely that properties of tire bales fabricated using a different tire baler, or prepared with the same equipment but different procedures, will show somewhat different results. It is also pertinent that performance of in-service tire shred fills often have a better

physical performance than would be predicted by the observed laboratory behavior of small specimens.

In order to integrate tire bales into a recognized standard of Civil Engineering practice, future projects must include laboratory tests and prototype field test sections that will allow development of reliable statistical relations that describe the variance of the measured properties and the real in-service performance. As indicated in Section 8.4, a comprehensive standardized product specification for fabrication of tire bales should be developed for consistence of the delivered materials. For projects using standardized products, a limited amount of testing (e.g., dimensional variation and unit weight) is required to characterize the materials and verify conformance to the draft tire bale specifications. If tire bales are produced by an alternate method, then more extensive test should be performed (e.g., compressive strength and creep in addition to the conformance testing). As discussed in the specification Section 6.3 Manufacturer's Quality Assurance (MQA) should include the requisite tire bale tests to provide data that adequately describes the tire bales used to construct the prototype test sections.

9.1 Recommended field testing

As discussed in Section 8.4, several design and performance-related issues require further evaluation. In the authors' opinion, use of tire bales as a core fill in embankments can be best evaluated in an instrumented prototype embankment structure, ideally as part of an actual project.

The field prototype should be constructed with at least two sections, each at least 15 m (50 ft) long. In one test section the tire bale portion of the embankment should be in filled with sand (or flowable fill) and in the other test section a geotextile separator should be placed above and beneath the tire bale section with no infill material placed inside or between the tire bales. A possible third test section could be constructed using the alternate infill material (i.e., either flowable fill or sand) that was not used in the first test section to provide a constructability and performance comparison of the infilling procedures.

For the primary test sections, tire bales should be placed a minimum of three layers deep and placed in a stacked brick arrangement. Other sections could be constructed to evaluate the impact of different layer thickness. For example, a ramp could be constructed at one end of the test embankment with an increasing number of tire bale layers to evaluate the maximum number of tire bale layers that could be practically used in an embankment. Similarly, the thickness of a compacted soil buffer layer above the tire bales could be evaluated by increasing the thickness of the buffer layer from each end of the test embankment to the middle. Constructing the thickest soil buffer above the middle test section will allow transition from one tire bale test section to the next and provide some insight into the behavior of the soil buffer layer and long-term compression and rebound of varying layers (thicknesses) of the tire bale zones.

The instrumentation program for each section is outlined in Table 9.1, and includes the tire bale issues to be monitored along with the appropriate instrumentation for making the measurements. The specific type and location of the instruments will depend on the specifics of the prototype test embankment including the location in relation to accessibility and power sources, purpose (e.g., roadway support or temporary construction access, and dimensions (i.e., length, width, and height).

The cost of the instrumentation for each section is anticipated to be basically the same, regardless of the prototype. However, there will be some anticipated savings if the prototypes are staged such that data acquisition equipment can be shared. Based on the monitoring program outlined in the table, the instrumentation for each test section should cost on the order of \$20,000 including procurement, installation and calibration. An additional \$20,000 should be budgeted for onsite instrumentation specialist and support personnel for each prototype section to provide on site consultation during construction and reading, reporting, interpreting and maintain the instrumentation program. The estimated costs do not include the costs of embankment design, construction, and associated material costs, nor do they include the cost of data interpretation and a final research report.

Table 9.1 Instrumentation program to monitor tire bale issues for embankment fill applications.

Tire Bale Issues	Measurement	Magnitude	Potential Instruments
Confirmation of fabrication requirements for the “Standard Type I tire bales”	Must document the fabrication & characteristics of a “Standard” tire bale.	N/A	Eyes, photographs and lab tests to document conformance with specification requirements.
Deformation during construction	Compression during construction and subsequent traffic loading	15% of tire bale thickness or approximately 150 mm (6 in.) during construction & short-term settlement	<ul style="list-style-type: none"> - Survey during construction after placement of each lift. - Settlement plates below and above tire bales extended to the surface. - LVDT’s with data acquisition to monitor deformation during traffic loading. - Compression with depth could be evaluated with settlement plates also placed between tire bale layers. - Horizontal profilers could also be used if cost is not an issue
Creep during service life	Long-term monitoring of vertical settlements	25 to 50 mm (1 to 2 in.) (depends on thickness of tire bale embankment)	Settlement plates above and below tire bales extended to the surface with LVDT’s and remote data acquisition to evaluate movement during temperature change and check surface deformation.
Relaxation or vertical expansion and lateral pressure exerted by tire bales if confining tie wires break or relax.	Vertical heave and lateral pressure between bales (cut bale wires at a min. of 2 locations after construction)	50 mm (2 in.) 9kN (2 kips)	<p>Settlement plates below and above tire bales extended to the surface.</p> <p>Place load cells with large seating plates between bale to be cut and adjacent bale(s)</p>
Internal and external shear strength values as function of tire bale interlock, surface asperities, separation materials, and unit weight.	Measure by pullout tests on tire bales in the field	N/A	N/A
Tire bale permeability	Observe water flow through tire bale section in field during rain events	N/A	Visual, on site rain fall measurements and outflow measurements from drainage system.
Requirements for soil buffer layer thickness	Visual and evaluation based on other measurements	N/A	Visual and surveyed response.

Table 9.2 Instrumentation program to monitor tire bale issues for embankment fill applications (continued)

Influence of soil buffer on pavement design	Load and deflection response	CDOT subgrade requirements for pavements	FWD and plate load test performed on buffer layer.
Requirements for geotextile separation/filters to minimize soil movement (loss of ground) into internal voids in tire bales	Use Class I geotextiles in test section with no in fill and excavate after construction	Holes in geotextile and loss of strength	Visual and surveyed response. Take samples and run wide width test ASTM D 4595.
Exterior protection	Evaluate alternative soil, rock and vegetation cover	N/A	Eyes, photographic, and survey techniques to provide accurate response records and data.
Exterior facing	Not required for embankments, but could evaluate vegetation growth	N/A	Eyes, photographic, and survey techniques to provide accurate response records and data
Temperature effects and fire protection	Thermal monitoring of the system	5 to 60° C (40 to 140° F)	- Strings of thermistors located every 300 mm (1 ft) vertical placed during construction on tires or after installation (through embankment into underlying soil). - Thermocouples placed (during construction) internal and external of tires, also monitor ambient temperature.
Long-term moisture absorption (and associated weight gain)	Long-term monitoring of humidity and moisture level within the tire bale system	0 to 10 % moisture content and 50 to 100% relative humidity	- Moisture sensors (TDR, gypsum blocks, etc) - relative humidity gage - Drill hole and sample (periodically)
Frost protection (If site location permits)	Long-term monitoring of frost penetration with depth in the tire bale system	-20 to 40° C (0 to 100° F)	- String(s) of thermistors placed vertically after construction at 100 mm (4 in) intervals to monitor temperature with depth. - Surface survey of road.
Long-term performance of pavement constructed over tire bale embankments	Ride quality and load/deflection response	Standard pavement requirements	- Periodic FWD and Benkelman beam tests (consult with pavement group). - Periodic distress surveys

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

This research study concludes that compacted tire bales systematically placed as the core of highway embankments is another technically and economically feasible use of scrap tires. The steady development and sales of tire balers, as well as the small-scale installations completed in the past 15 years, indicates there are a wide range of applications for properly fabricated tire bales. Compacted tire bales are considered a lightweight engineered fill, with properties similar to, and often better than the typical lightweight materials which have been successfully used by Civil Engineers for the past 30 years. Tire bales, as listed in Table 2.1, have been used in wall systems, slope repair systems, lightweight embankments, drainage zones, erosion protection walls, and rockfall and crash barriers. The Case Studies in Appendix B illustrate recent uses in transportation applications.

Typical tire bales weigh approximately 8.9 kN (2,000 lb), the dimensions range from 0.7 m to 1.5 m (2.5 ft to 5 ft), and the unit weights range from 5.5 to 8.8 kN/m³ (35 to 50 pcf). The compacted tire bale is typically bound by several wire tires to maintain the block form and provide the inherent strength and properties of each tire bale. This size, weight, and tie system provides reasonable dimensions, and weights that can quickly handled by small wheeled / tracked fork lift equipment.

The tire bale properties include low unit weight, specific gravity greater than 1.0 (sinks in water), modest compressibility (2 to 10 % strain at working stress levels) and creep values, high internal and external shear strength, relatively high permeability, low thermal conductivity, low leaching potential, low potential for developing exothermic reactions, and high chemical and physical durability as described in Section 4 and listed in Table 4.1.

The laboratory test program, conducted as a companion study to the feasibility analysis and report, was very successful and provided a number of property values that had not been previously measured and reported for typical tire bales. The test results in Appendix D, and the presentation of typical test results in Section 4, provide a starting point for an engineered design

approach for tire bale embankments. Additional Quality Assurance and Quality Control testing should be conducted for each instrumented prototype field tire bale test section in order to relate measured performance to the measured characteristics of the tire bales fabricated for each test embankment. Similar tests should be conducted on tire bales fabricated for routine embankment projects to develop a statistical evaluation of the standard deviation values and variability of the important properties of tire bales.

The preliminary estimates of the net cost of \$3.70 to \$9.70 /m³ (\$2.80 to \$7.40 /cy) indicate a tire bale embankment zone could result in a cost savings as compared to the use of embankment backfill. Embankment backfill was found to have an average cost of \$12.60 /m³ (9.60 /cy) on approximately 50 percent of the 125 Colorado projects in the 2001 to 2003 time period where the volume of the embankment fill ranged from 3,270 to 38,210 m³ (2,500 to 50,000 cy). The estimated cost of a tire bale fill is at the low end of the range of costs reported for other lightweight materials, such as EPS blocks, foamed concrete, shredded tires, and fly ash / slags.

However, there are some fabrication, design, construction, and performance issues that must be addressed in order to develop an established basis for engineered approach to design and construct a tire bale embankment that will provide satisfactory performance for the service life of the project. This situation is typical of the engineering process for any new material or application where manufacturing and fabrication requirements must be established, followed by laboratory and field testing to determine the material properties the designer must use to develop the project plans and specifications. Finally, prototype structures must be instrumented and monitored to measure a structure's performance in comparison to the design expectation.

The important issues that must be addressed are listed in Table 8.1 and summarized below. The issues include:

- understanding the appropriate level of fire protection required, commensurate with the level of risk and costs associated with use of tire bale embankment zones in transportation applications.
- developing specifications for consistent fabrication of tire bales with the desired properties.

- understanding product variability resulting from changes in fabrication procedures and the use of different tire balers.
- defining the short-term and long-term requirements for bale ties and the potential impact of broken wire tires on the lateral restraint requirements for the embankment.
- understand variations in internal and external shear strength, and compressibility and creep rates, as a function of fabrication procedures and applied loadings.
- developing properties and dimensions for Class I and Class II Tire Bale Embankments
- developing requirements for geotextile separation layers.
- selecting type and thickness of buffer layers between tire bales and the overlying pavement.
- interactions with existing and future utility penetrations.
- selecting soil / rock covers, facing, and protection on variable angle side slopes for specific site and service conditions.

10.2 Recommendations

The continuing evaluation of tire bales in transportation embankments is strongly recommended. Previous sections of this report have outlined and tabulated in detail the “state of practice” and the feasibility of using tire bale embankments, in comparison to other lightweight fill materials and in contrast to, the conventional CDOT use of embankment backfill. The previous sections outlined recommendations that are “next steps” to implement and improve the state of practice for tire bale embankments. These next steps are intended to provide additional information on the relation of fabrication procedures to tire bale properties (see Section 4.3), design guidelines (see Table 6.2), specifications (see Section 6.3), costs (see Table 7.1 to 7.3), fire protection issues (see Table 8.3), and in-service issues such as creep (see Table 9.1).

The following tasks are recommended by the authors as an efficient and effective sequence to follow in implementing the recommendations developed by this study to obtain the information required to develop the state of practice for this application of recycled scrap tires.

Task 1 Construct several prototype tire bale embankment with different cross-sections as part of a highway embankment on a secondary highway. (See Section 9) This would involve:

- (a) selecting an appropriate site.
- (b) preparing a comprehensive tire bale specification, including fabrication and QC guidelines.
- (c) testing selected tire bales for basic mechanical and chemical properties.
- (d) developing design guidelines and formulas, performance requirements, and safety factors.
- (e) selecting instrumentation as recommend in Table 9.1.
- (f) preparing design drawings and cost estimates.
- (g) constructing instrumented cross-sections as recommended in Section 9.
- (h) conducting FWD evaluations of soil buffer layers and pavement system.
- (i) preparing as-built plans and reports of the construction monitoring.
- (j) monitoring in-service performance of the prototype sections (a five-year program is recommended, including FWD testing at 3 month intervals for the first year and once a year thereafter.
- (k) preparing annual reports on in-service performance

After constructing the prototype test sections, and simultaneously with monitoring the performance of the test sections, address geotechnical engineering design methodology and fire protection engineering.

Task 2.1 Conduct engineering studies that develop a comprehensive design methodology for constructing tire bale embankments, including:

- (a) fabrication procedures in relation to tire bale properties.
- (b) prepare documented case histories of the prototype sections along with other successful and problematic tire bale installations, including design assumptions, construction details, and measured performance.
- (c) quality control requirements and responsibilities.
- (d) design methods, analyses, details, and examples.
- (e) construction practices and requirements.

- (f) impacts on pavement design.
- (g) use of ancillary materials, such as bale ties, soil / rock slope covers, and facing options.
- (h) cost studies and estimates to optimize costs v. benefits in the design construction process.
- (i) specifications and related AASHTO / ASTM standards, for Class I, Class II tire bale embankments, (including fire protection requirements developed in Task 2.2.)
- (j) monitoring long-term in-service performance.
- (k) guidelines for use of tire bales in other applications,(such as slope stability, erosion protection for lakes, rivers, streams, and rock-fall barriers.)

Task 2.2 Simultaneously with Task 2.1, conduct a fire engineering study to evaluate the potential in-service fire risks associated with tire bale embankments. This could involve:

- (b) selection of experienced and qualified fire engineering consultants.
- (c) review and report of pertinent literature that assesses the fire risks and protection required for in-service tire bale embankments.
- (d) review temperature data obtained from the prototype tire bale embankments test sections to determine if observed temperature changes are (1) similar to the temperature observations in fresh tire shred fills, and (2) indicate the possibility of that significant exothermic reaction could develop and initiate tire bale fires.
- (e) develop a report, including appropriate recommendations (as required) and cost estimates for field fire tests of selected materials and tire bales to replicate in-service conditions.
- (f) prepare a report with recommendations for fire protection requirements for in-service tire bale embankments.
- (g) prepare fire protection requirements for tire bale embankment specifications, based on the work described in Task 2.2 (a) to (e)

Task 3 Ultimately, it may be appropriate to develop a national oversight panel consisting of the stakeholders in the tire recycling industry that are interested in and can champion the continued development of tire bale applications. The panel could include 1) tire baler manufacturers, experienced geotechnical design engineers familiar with tire bales and lightweight fills, instrumentation, and transportation applications, 2) transportation contractors, 3) experienced academic researchers familiar with behavior of rubber materials and fire protection requirements, 4) governmental agencies, and 5) industry agencies, such as Rubber Manufacturer’s Association and Waste Recyclers. This group would solicit funding, select outside consultants, and guide the process of rapidly developing the “state of practice” to a point where tire bale materials are routine in Civil Engineering practice and quality materials are readily available at a reasonable cost.

REFERENCES

- AASHTO M288, (1997). "Standard Specifications for Geotextiles – M288", Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 18th Edition, American Association of State Transportation and Highway Officials, Washington, D. C.,
- ASTM, (1998). ASTM D 6270-98, "Standard Practice for Use of Scrap Tires in Civil Engineering Applications," American Society of Testing and Materials, West Conshohocken, PA
- Baker, T. E., T. M. Allen, D. V. Jenkins, Mooney, D. T., Pierce, L. M., Christie, R. A., Weston, J. T., (2003). "Evaluation of the Use of Scrap Tires in Transportation Related Applications in the State of Washington", Report to the Legislature as Required by SHB 2308, Environmental and Engineering Programs Division, Materials Laboratory, Olympia, WA.
- Benson, C.H., M.A. Olson, and W.R. Bergstrom, (1996). Temperatures of an Insulated Landfill Liner, Transportation Research Board, 75th annual meeting, Washington, D.C.
- Blumenthal, M., Rubber Manufacturer's Association, (2004). Personal Communication
- Bosscher, P.J., T.B. Edil, and N. Eldin, (1993). "Construction and Performance of Shredded Waste Tire Test Embankment," Transportation Research Record No. 1345, Transportation Research Board, Washington, D.C., pp. 44-52.
- Bosscher, P.J., T.B. Edil, and S. Kuraoka, (1997). "Design of Highway Embankments Using Tire Chips," Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 4, April 1997, pp. 295-304.
- Caltrans (1988) "The Use of Discarded Tires in Highway Maintenance", Translab Design Information Brochure No. TI/REC/1/88, California Department of Transportation, Sacramento, CA
- Chautauqua County, (2001). "Utilization of Scrap Tires in Baled Form Used in Roadbed Construction in Conjunction with the Tire Amnesty Program." Chautauqua County Department of Public Facilities, Division of Transportation.
- Chautauqua County Department of Public Works, New York, (2002). "Where the Rubber Really Meets the Road, Chautauqua County New York Scrap Tire Reduction Program, Using Scrap Tires in Roadbed Construction, Tire Amnesty Program", CD-ROM.
- Christopher, B.R., (2002). Personal photo.

- Edil, T.B., and Bosscher, P.J., (1992). "Development of Engineering Criteria for Shredded or Whole Tires in Highway Applications," Report No. WI 14-92, Department of Civil and Environmental Engineering, University of Wisconsin, Madison, WI,
- Edil, T.B., and Bosscher, P.J., (1994). "Development of Tire Shreds and Soil Mixtures," *Geotechnical Testing Journal*, Vol. 17, No. 4, December, pp. 453-464.
- Encore Systems, (2003, 2004). Personal communication. Photo courtesy of Encore.
- Enviroblock, www.enviro-block.com
- EPA, (1991). "Summary of Markets for Scrap Tires," Report No. EPA/530-SW-90-0748B, US Environmental Protection Agency, Washington D.C., pp. 1-12.
- Eaton, R. A., Roberts, R.J., and Humphrey, D. N.,(1994). "Gravel Road Test Sections Insulated with Scrap Tire Shreds," Special Report 94-21, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH August 1994.
- Northern Tyre (UK) Limited, Inverness, Scotland, (2004). www.northerntyre.co.uk/projects.htm
- Integrated Waste Management Board, (2002). "Tire Pile Fires Prevention, Response, Remediation", prepared by Environmental Engineering and Contracting, Santa Anna, CA.
- Foose, G.J., C.H. Benson, and P.J. Bosscher, (1996). "Sand Reinforced with Shredded Waste Tires," Journal of Geotechnical Engineering, Vol. 122, No. 9, September 1996, pp. 760-767.
- GeoTesting Express, (2004). "Laboratory Testing of Tire Bales," A report prepared for the Colorado Department of Transportation by GeoTesting Express of Georgia, Roswell, Georgia.
- Geisler, E., W.K. Cody, and M.K. Niemi, (1989). "Tires for Subgrade Support," Annual Conference on Forest Engineering, Coeur D'Alene, ID 5 pp.
- Hoppe, E.J., (1998). "Field Study of Shredded-Tire Embankment," Transportation Research Record No. 1619, Transportation Research Board, Washington D.C., pp. 47-54.
- Humphrey, D.N., (1996). Investigation of Exothermic Reaction in Tire Shred Fill Located on SR 100 in Ilwaco, Washington, Prepared for Federal Highway Administration, Washington, D.C.
- Humphrey, D., and W. Manion, (1992). "Properties of Tire Chips for Lightweight Fill," Proceedings of the 1992 ASCE Specialty Conference on Grouting, Soil Improvement and Geosynthetics, Vol. 2, No. 30, ASCE, New York, N.Y., pp. 1344-1355.

- Humphrey, D.N, (1998), “Highway Applications of Tire Shreds”, Sponsored by: New England Transportation Consortium, Worcester, MA, December 1, 1998.
- Humphrey, D.N., Katz, L.E., (2001), “ Five-Year Study of the Water Quality Effects of Tire Shreds Placed Above the Water Table”.
- Liu, H.S., Mead, J.L., and Stacer, R.G., (1998). “Environmental Impacts of Recycled Rubber in Light Fill Applications: Summary and Evaluation of Existing Literature,” Chelsea Center For Recycling and Economic Development, Massachusetts.
- Masad E, Taha R, Ho C, Papagiannakis T. (1996) “Engineering Properties of Tire/Soil Mixtures as a Lightweight Fill Material” ASTM Geotechnical Testing Journal, ASTM International, West Conshohocken, PA.
- NFPA 231 D, (1998) “Standard for Storage of Rubber Tires – 1998 Edition”, prepared by Technical Committee on Rubber Tires, effective August 5, 1998, National Fire Protection Association, Inc., Quincy, MA.
- Oosterbaan, M.D. (1963) “Investigation of Foamed Plastic as an Insulating Layer in Highway Pavements, M.S. Thesis, Purdue University, Lafayette, IN.
- O’Shaughnessy, V. and V.K. Garga, (2000). “Tire-Reinforced Earthfill. Part 2: Pull-Out Behavior and Reinforced Slope Design,” Canadian Geotechnical Journal, Vol. 37, pp. 97-116.
- RMA, (2002). “U.S. Scrap Tire Markets 2001,” Rubber Manufacturers Association, Washington, D.C.
- Rooke, L., (2001). “Building Dams From Baled Scrap Tires,” Biocycle, Vol. 42, p. 74.
- Scrap tires www.scraptirenews.com
- Senadheera, Sanjay. (TxDOT, 2002).
<http://www.ce.ttu.edu/centers/techmrt/home/researchproj/Geotech/ScrapTires.html>
- Shock, A., R. Zeck, R. Sandusky, and D. Hudson, (2001). “Thermal Modeling of Tire Bales,” submitted to Dr. Robert Knecht, Colorado School of Mines, June 13th, 2001.
- Stark T.D, D. Arellano, J.S. Horvath, and D. Leshchinsky, (2000), “Guidelines for Geofoam Applications in Embankment Projects”, by National Cooperative Highway Research Program, Project No. 24-11, Final Report, August 2002.
- Touch the Earth Construction, “Tire-house Builders: No More Pounding!!!” (2004),
www.touchtheearthranch.com/tires.htm

TXDOT (2004) “Validate the Effectiveness of Tire Bale Use in Slope Repairs and Embankment Construction,” Project No. 5-9023-01, Texas Department of Transportation.

TXDOT, TCEQ, (2001). “Progress Report on Using Scrap Tires and Crumb Rubber in Highway Construction Projects,” 76th Legislative Session TCEQ-Rider 24 and TXDOT-Rider 47. Texas Department of Transportation, Texas Commission on Environmental Quality.

TXDOT, TCEQ, (2003). “Progress Report on Using Scrap Tires and Crumb Rubber in Highway Construction Projects,” 77th Legislative Session TCEQ-Rider 19 and TXDOT-Rider 44. Texas Department of Transportation, Texas Commission on Environmental Quality.

Tirebaler <http://tirebaler.com>

Transportation Research Board: <http://rip.trb.org>

U.S. Fire Administration, “Scrap and Shredded Tire Fires, Special Report”, Report 093 of Major Fires Investigation Project, researched by Stanley L. Poole, Jr. and edited by Hollis Stambaugh and Peter Banks, conducted by Varley-Campbell and Associates, Inc./TriData Corporation under contract EMW-94-4423 to the Federal Emergency Management Agency, (1998).

Welle, R., (2004) Front Range Recycling, personal communication.

Williammee, R., (2004) Personal communication

Williamson, R. B., (2004) Personal communication

Williamson, R.B. and Schroeder, R.A., “Fire Safety Assessment of the Scrap Tire Storage Methods”, Interdisciplinary Graduate Program in Fire Safety Engineering Science, Civil and Environmental Engineering, University of California, Berkeley, CA in proceedings INTERFLAM '96, Interscience Communications, London, England pp 89-101 (1996).

Wu, W.Y., C.C. Benda, and R.F. Cauley, (1997). “Triaxial Determination of Shear Strength of Tire Chips,” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No 5, pp. 479-482.

Zornberg, J.G., A. Cabral, and C. Viratjandr, (2003). “Behaviour of Tire Shred-Soil Mixtures.” Accepted for publication in the Canadian Geotechnical Journal.

Zornberg, J.G., Costa, Y., and Vollenweider, B. (2004). “Mechanical Performance of a Prototype Embankment Backfill Built with Tire Shreds and Cohesive Soil.” Proceedings of the 83rd Annual Meeting, *Transportation Research Board*, January 11-15, Washington, D.C.

World Wide Web Sites , relevant information on scrap tires

http://www.epa.gov/jtr/jtrnet/tire_conv.htm

www.epa.gov/recycle.measure/conversn.htm

www.tfhrc.gov/hnr20/recycle/waste/index.htm

www.cwc.org/tirest954.htm

(scrap tire density)

www.co.chautauqua.ny.us

<http://www.scraptirenews.com>

(571.258.0500)

www.wasteage.com

<http://www.scraptirenews.com/99apr3.html>

(Iowa landfills use tire chips)

(Rubber core sound wall for I-675, Centerville, Ohio)

<http://www.ciwmb.ca.gov/Publications>

(CA landfills use tire shreds)

www.tirebaler.com

(Encore tire baler, 218.328.0023)

<http://www.northerntyre.co.uk>

<http://www.ecoflex.com.au>

[http://useit.umeciv.maine.edu/.](http://useit.umeciv.maine.edu/)

(Beneficial Use of Solid Waste in Maine, University of Maine)

**Report No. CDOT-DTD-R-2005-2
Final Report**

APPENDICES

TIRE BALES IN HIGHWAY APPLICATIONS: FEASIBILITY AND PROPERTIES EVALUATION

Jorge G. Zornberg, Ph.D., P.E.

Barry R. Christopher, Ph.D., P.E.

Marvin D. Oosterbaan, P.E.



March 2005

**COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH**

APPENDIX A. TIRE BALE APPLICATIONS FOR CIVIL ENGINEERING PROJECTS

Although the use of tire bales in civil engineering applications has been relatively limited to date, they have been used in some other applications. For example, tire bales have been extensively used as wind breaks for livestock on farms. In such applications, tire bales are generally stacked to the desired height, usually 1.2 m to 1.8 m (4 to 6 ft), and are not treated with any particular facing or reinforcing material. Tire bales are frequently used in a similar manner to construct non-structural walls.

The use of tire bales for erosion control has offered good results. However, little published information has been reported on the design criteria for such application. A large project in which tire bales were implemented as erosion control is the restoration project along Lake Carlsbad in New Mexico. A 1,220 m (4000 ft) long section of the shoreline was protected against erosion by the use of tire bales. The bales were laid in a wet concrete leveling pad, and then covered in shotcrete. Backfill material was then placed behind and on top of the treated bales, upon which a pedestrian sidewalk was ultimately constructed. According to reports based on visual inspections of the project, the tire bales have performed extremely well, and plans for use of tire bales in future erosion-control projects along the lake are being undertaken. A view of the tire bales during the construction process is shown in Figure A1.

Another civil engineering application in which tire bales have been used is for the construction of earth dams. For example, tire bales were used as lightweight fill on both the upper and lower sides of the clay-core dam in Mountain Home, Arkansas (Biocycle, 2001). Tire bales were placed in lifts one bale deep; each lift was covered with compacted clay and granular soil. When the desired height was reached, the tire bales were ultimately capped with a layer of compacted soil. Initial reports based on visual inspections of the dam indicate that the bales are performing extremely well.



**Figure A1. Tire Bales as Erosion Control
(during construction)**

APPENDIX B. CASE STUDIES OF TIRE BALE APPLICATIONS FOR TRANSPORTATION PROJECTS

CASE STUDY 1: SLOPE REPAIR TEXAS

Tire bales have been reportedly used for remediation of a slope failure in Texas (Richard Williammee, 2002, email communication). Specifications for tire bale embankments are currently under development by the Texas Department of Transportation (See Appendix D). Construction recommendations include placement of a 12 in granular base drainage layer at the bottom of the embankment before placing the tire bales as shown on the typical sections. The granular base layer should be extended sufficiently to allow water to freely drain away from the embankment structure. The specifications also called for embankment construction to minimize infiltration of water and air into the tire bale fill. Use of restraining straps in the longitudinal direction of the roadway is recommended. In addition, the proposed specifications require placement of an 8 inch compacted soil layer between each tire bale layer. Use a soil with a PI less than 35 is required to provide a cushioning layer between successive layers of tire bales. Use of a geomembrane is required over the final layer of the tire bales in order to provide longterm durability to the embankment. Finally, an 18 inch minimum thick mineral soil layer free of organic matter should be placed on the side slopes.

CASE STUDY 2: CONDIN ROAD, CHAUTAUQUA COUNTY, NEW YORK

Condin Road, located in Chautauqua County, NY was originally constructed over wet clay soils in the late 1800s. Ever since, the gravel road has experienced significant problems associated to freeze/thaw cycles each winter. In addition, growing concerns have been reported in Chautauqua County regarding the size of stockpiles of scrap tires. Specifically, many illegal tire dumps within the county had posed a threat to the environment as well as health related problems to the local population. Consequently, action was then taken by the county to use scrap tires productively. Specifically, a research development and demonstration project was permitted by the New York State Division of Environmental Conservation in which tire bales were to be used as replacement sub-grade fill for a portion of the road in 1999 (Scrap Tire News, 2002). A Beneficial Use Determination was issued by the New York DEP in January 2003 (See Appendix 8.5).

The project involved the excavation of 1000 feet of the existing road subgrade, and replacing it with tire bales. After the excavation, a nonwoven geotextile was placed over the in-situ soil. On top of this geotextile, tire bales were placed in a brick-like fashion to form the core of the roadbed structure. Voids within the tire bales were filled with coarse sand, which was compacted using traditional methods (a vibratory roller was used). Finally, three 6-inch gravel lifts were placed on top of the tire bales, with each lift compacted also using vibratory methods. A view of the construction process is shown in Figure B1.

After the first winter following completion of construction of the test section of the road, the results indicated that the test section performed much better than the rest of the road. Significant damage was observed at several locations along the rest of the road, while no damage was observed along the tire bale test section.

According to the Chautauqua County Public Works Director, the section of road that utilized the tire bales performed better through the rain, snow, and heavy traffic than ever before. Although the test embankment was not outfitted with instrumentation, the success of the project has been attributed to three main factors (Encore Systems, Inc.).

First, while the bearing capacity of the tire bale layers was not quantified, its magnitude is certainly well above that of the subgrade soils.

Second, the good drainage characteristics of the tire bales, which facilitate flow of infiltrating liquids through the tire bales, promoting drainage into lateral trench drains.

Finally, the insulation of the tire bales, which were reported to protect the sub-base from frost-damage.

More than 250,000 waste tires were used in this project. Following this successful application, permits have been granted to implement similar county projects.

Chautauqua County prepared the the following summary "Utilization of Scrap Tires in Baled Form Used in Roadbed Construction in Conjunction with the Tire Amnesty Program" to describe their experience detail the cost savings associated with their application of baled tires on the sections of roadways completed from 1999 to 2002..



Figure B2. Construction of a Road Embankment Using Tire Bales as Subgrade



CHAUTAUQUA COUNTY, NEW YORK DEPARTMENT OF PUBLIC FACILITIES

Kenneth B. Brentley, Director
Kenneth P. Smith, Deputy Director – Transportation
454 North Work Street • Falconer, NY 14733
(716) 661-8400

Utilization of Scrap Tires in Baled Form Used in Roadbed Construction in Conjunction with the Tire Amnesty Program

SCOPE AND DESCRIPTION OF PROJECT

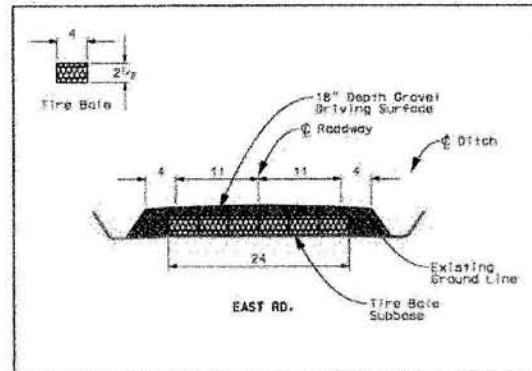
Clearing Chautauqua County's of scrap tires through a "tire amnesty" program, while beneficially reusing the tires in baled form in roadbed construction as a cost-effective alternative to a typical stone drainage layer when used in areas of marginal (wet) soils.

HISTORY OF THE PROGRAM

On April 23, 1995, Chautauqua County faced environmental disaster as millions of tires burned on a rural hillside in the Town of Charlotte. Over the next 72 hours, hundreds of firefighters and highway personnel risked their lives to contain the inferno, operating with near zero visibility because of the dense black smoke. That fire nearly bankrupted several local fire departments and cost the Chautauqua County Department of Public Facilities more than \$62,000.

Even before the smoke cleared, County officials made a commitment to never expose the environment, residents or employees to such a risk again. With approximately 10 million tires dumped in the County, a mechanism was needed to clean them up.

Chautauqua County researched the entire scrap tire "industry" including markets such as commercial rubber products, civil engineering applications and fuel substitute/supplements. Tire shredding was investigated and it was determined that the entire investment, not including maintenance, would cost between \$3-5 million. The Rubber Manufacturers Association indicated that the market for tire-derived crumb rubber was poor, and the supply exceeded any demand.



Chautauqua County was introduced to the concept of baling whole tires in a visit to a 40 million tire dump in southern Ohio. The operators had purchased a portable baler which hydraulically compressed 100 light truck or passenger tires into a one-ton block. The baler manufacturer, Encore Systems, was contacted and it was learned that tire bales were being used in many civil engineering applications in the United States including streambank stabilization, retaining walls, and erosion control. Encore Systems then introduced the idea of using whole baled tires in road subgrade. In wet soils the tire bales can be used to effectively float over marginal areas. The tire bale road base would be engineered to work as efficiently as gravel subgrades at less financial and environmental cost.

In 1998, discussions began with the New York State Department of Transportation (NYSDOT) and the New York State Department of Environmental Conservation (NYSDEC) regarding permitting of the use of whole baled tires in two road demonstration projects. On September 28, 1998, the Research, Development and Demonstration permit was granted.

PROGRAM ACHIEVEMENTS

Initial Clean up of a Large Tire Dump

Chautauqua County began baling whole scrap passenger and light truck tires on October 28, 1998 at a site in the Town of Poland referred to as the Levant Tire Dump. This initiative was spearheaded by the County Department of Public Facilities and the County Department of Environmental Health as a means to eliminate the threat of a tire fire at this location. The dump was adjacent to residences, a recharge area for the Cassadaga Valley Aquifer, two major State highways and a church and school complex. In addition, the site's soggy soils and limited access would have made mobilization of fire fighting equipment nearly impossible. Manual labor for transporting the tires to the baler was provided by inmates of the Chautauqua County Jail. County employees, as well as employees of our partner town and villages, operated the baler, the trackhoe to dislodge the muddy and wet tires and the loader to catch the tires from the baler and place on the lowboy for transport to the County Landfill in Ellery, the location specified in our permit adjacent to one of the road demonstration projects.

In making this project a reality, Chautauqua County, the New York State DOT and the New York State DEC worked together and were able to implement an unprecedented use of scrap tires in a relatively quick period of time. The Sheriff's Department provided between 4 and 6 inmates daily who had the unenviable task of manually lifting thousands of tires per day and hand loading them into the baler. On September 17, 1999, the last of the 154,000 tires at Levant were baled and by September 28, 1999 the site was graded and seeded.

Cleaning up Smaller Stockpiles from Municipalities and Residents

Tire Amnesty Program

Due to the high cost of scrap tire disposal, most of Chautauqua County's rural towns and villages had their own small stockpiles of tires at their highway barns. In addition, many towns also had the problem of tires dumped illegally along their roadsides and stored in residents' yards. Using the County Landfill as a centralized tire collection site, the County offers a Tire Amnesty program, now in

its third year, for these towns, villages, and cities. The scrap tires are brought to the Landfill by each municipality, free of charge, where they are baled and stored for use in the roadbed construction projects. Working at a steady pace, two operators can bale four to six hundred tires an hour. As done at the Levant clean-up, the Chautauqua County Department of Public Facilities working in conjunction with the Sheriff's Department, uses low-risk prison inmates as labor. In addition to the towns and villages participation, in 2001 and 2002, the County allowed tires from small tire dumps (5,000 tires or less) to be brought to the Tire Amnesty collection point, thus eliminating most of Chautauqua County's remaining tire dumps.

Tire Bales in Roadbed Construction

Four roads have been built using the bales.

- ✓ **Condin Road, Town of Ellery**
- ✓ **Kabob Road, Town of Stockton**
- ✓ **East Road, Town of Charlotte**
- ✓ **Sanford Road, Town of Cherry Creek**

Condin Road, Town of Ellery

The tires baled from the clean-up of the Levant Tire Dump were used in our first demonstration project in the summer of 1999. Condin Road is a gravel road that is used by large trucks accessing the leachate ponds on the County Landfill's property. This road had always been troublesome. Due to its location on a hillside, the poor drainage of the soils below, and the heavy truck traffic, a section of this road would continually erode and needed to be graded often. 120,000 tires or 1,200 bales were used in the replacement of the subgrade in a 928' section. The road surface was excavated 2' below finished grade, geofabric laid, and the 1,200 bales were placed 6 bales wide by 200 bales long on top of the fabric. Covering the bales was 2,500 tons of sand to fill the voids as much as possible. This process not only serves as a free draining system, it also locks each bale into place forming a non-shifting layer. A vibratory roller was used to compact the sand, then three, 6" lifts of gravel were laid again being compacted by the vibratory roller. The adjacent land was seeded and mulched for erosion protection and stabilization purposes. Condin Road, the first road in Chautauqua County

to be built over a base of tire bales has proven itself to not only be durable, but a significant improvement from the problem road it had been in the past.

Kabob Road, Town of Stockton

Kabob Road is a well-used paved county road with a daily traffic count of 740 as recorded by the Chautauqua County Department of Public Facilities Engineering personnel. It is used very often as an alternative route to busy NYS Route 60, which is the major north-south artery through Chautauqua County linking I-90 and I-86. In October of 2000, the Kabob Road was scheduled to be blacktopped. It had a 200 foot banked curve which had been a perennial trouble spot...it just couldn't hold the pavement on that stretch. The sub-base of the road was very poor. The road was originally built on a marsh and the roadbed consisted of marginal wet clay-type soils. The freeze/thaw cycle would heave and break the pavement. Before the County spent the money on blacktop, the sub-base needed to be drastically improved. The tire bales were the perfect solution as the material for sub-base because of their free-draining characteristics, load handling capabilities and size. It was determined that the entire 200 foot section of the Kabob Road needed to be completely rebuilt. The roadbed was prepared similarly to that of Condin Road with the addition of a drainage pipe. 30,000 tires or 300 bales were placed side by side on the geotextile covered roadbed, sanded, rolled, and graveled. Unlike Condin Road which was left graveled, Kabob Road received 9 inches of blacktop. Kabob Road, the second road in Chautauqua County to be built over a base of tire bales and the first to be paved has proven itself to be very durable. In addition, the solving of its drainage problem has kept this section of road free from potholes and provides a safe surface for driving.

East Road, Town of Charlotte

East Road is a rural gravel road own by the Town of Charlotte bordered by State-owned lands with traffic counts averaging 100 vehicles daily, East Road was constructed years ago over very marginal soils. In spring, this road is very soft making travel difficult. A 1000' demonstration project using 120,000 tires or 1,200 bales to effectively bridge over this very poor base of marginal soils was completed in June 2001. The severe drainage problem and marshy soils of East Road have been conquered by rebuilding its base using tires bales and raising its surface. Although East Road has just made it through only one Chautauqua County winter, we are pleased to report that East Road is not only be passable, but now provides a safe and smooth ride through the picturesque town of Charlotte.

Sanford Road, Town of Cherry Creek

Reconstruction of the roadbed in an 1500' section of Sanford Road was completed in the summer of 2002. Sanford Road is a rural gravel road in the Town of Cherry Creek running through the Boutwell Hill State Forest. This road is frequently impassable during wet weather due to poor drainage, marginal soils and low lying sections. Sanford Road, originally a farm-to-market road was built over extremely poor soils. In the winter, water trapped in the soft soils freezes. During the spring thaw, the melted ice turns the road into a rutted, potholed mess as the base cannot support the weights of the vehicles traveling over it. The existing roadbed of Sanford Road was excavated down 24", geotextile fabric installed and underdrain where necessary. Baled tires were placed 5 across due to the narrower than usual road right of way and totally encapsulated within the road fill and covered with 18" of gravel. Approximately 150,000 tires in baled form were used for the 1,500' road project. Periodic maintenance of the gravel surface by the Town of Cherry Creek will ensure future long term road integrity.

THE NUMBERS

Tires Cleaned Up

1999	Levant Tire Dump	154,000
2000	Tire Amnesty I	145,200
	Tires from private collection site	17,500
2001	Tire Amnesty II	52,000
	Tires from small tire dumps	50,000
2002	Tire Amnesty III	61,000
	Tires from small tire dumps.....	32,282

TOTAL TIRES CLEANED UP TO DATE 511,982

Tires Used in Roadbed Construction

1999	Condin Road	120,000
2000	Kabob Road	30,000
2001	East Road	120,000
2002	Sanford Road	150,000

TOTAL TIRES USED IN ROADBED CONSTRUCTION 420,000

Program Costs and Savings

Taxpayer Disposal Costs per Tire		
	Normal cost for disposal at landfill	\$2.00 each
	Cost during program (includes costs for prison guard, baler operating costs, baling wires)	\$0.40 each
	TOTAL TAXPAYER SAVINGS PER TIRE	\$1.60 EACH

Taxpayer Disposal Costs for Entire Tire Amnesty Program		
	Normal cost for disposal at landfill	\$1,023,964.00
	Cost during program (includes costs for prison guard, baler operating costs, baling wires)	\$204,792.80
	TOTAL TAXPAYER SAVINGS FOR ENTIRE TIRE AMNESTY PROGRAM	\$819,176.00

Using Baled Tires in Roadbed vs. Stone		
	Cost of stone for 1000' of roadbed construction	\$24,050.00
	Cost of tires for 1000' of roadbed construction	\$21,000.00
	TOTAL TAXPAYER SAVINGS FOR 1000' ROADBED CONSTRUCTION	\$3,050.00

Using Baled Tires in Roadbed vs. Stone in 4 Completed Road Projects		
	Condin Road (928')	\$2,830.40
	Kabob Road (200')	\$610.00
	East Road (1000')	\$3,050.00
	Sanford Road (1500').....	\$4,575.00
	TOTAL TAXPAYER SAVINGS FOR ALL ROADBED CONSTRUCTION PROJECTS	\$11,065.40

PARTICIPATION

Chautauqua County now has the enviable reputation of being one of the few counties in New York State that has an excellent working relationship with the towns and villages located within its boundaries. Sharing services between the counties and its municipalities and between municipalities is commonplace and offers the taxpayers services that otherwise would not be available to them, with accompanying cost savings. The entire Tire Baling and Tire Amnesty programs would not have been possible without their cooperation.

During the Levant Tire Dump clean-up, each municipality sent one worker for a one week stint of operating the baler. Some municipalities even offered trucks and additional personnel to help, even though the tire dump had no impact on their communities. In return, the county offered the Tire Amnesty program to the municipalities. Each municipality offered their residents an important benefit at minimal cost to the municipality. There was not one town, village or city that did not participate.

Chautauqua County's tire program broke the boundaries between the municipalities and the county and unearthed the spirit of cooperation and communication that was buried deep within the heart of Chautauqua County.

APPLICABILITY IN OTHER MUNICIPALITIES and EXPECTED LIFE OF PROJECT

In October of 2001, Chautauqua County applied for a Beneficial Use Determination from the New York State Department of Transportation. When approved, this technology will be available for use without obtaining a separate permit for each planned project. Permitting, while a necessary safeguard for the environment, becomes a long drawn-out expensive process. We feel that we have proven this technology to be a safe, cost-effective and excellent method of reducing the numbers of scrap tires in New York State, which in turn will help curb the spread of the West Nile Virus and would prevent the environmental disaster of a large tire fire. When approved,

Chautauqua County plans to continue to offer the Tire Amnesty Program to county residents and will reconstruct roadbeds in other trouble spots within the county's highway system as long as scrap tires are available within our borders. In addition, we have offered to share our expertise with other municipalities that desire a cost-effective and beneficial method of scrap tire management.

BENEFITS

Taxpayers' Benefit

In addition to the obvious benefit of elimination of a health hazard and eyesore, Chautauqua County's scrap tire management program actually saved the taxpayers over \$830,241.00 during its first four years.

Environment and Health Benefit

Because of the density of the bales, the decreased surface area, and lack of air, the danger of another environmentally damaging tire fire was greatly reduced. In addition, tires in baled form do not hold water, thus the risk for the spread of the West Nile Virus was reduced as places for the mosquitoes to breed were eliminated.

Towns, Villages & Cities' Benefit

The Tire Amnesty Program was a chance for the municipalities to offer their residents an important benefit at no cost to the resident and minimal cost to the municipality.

County's Benefit

The success of this program proves that cooperation between the County and communities benefits everyone.

Department of Public Facilities Benefit

By using the tire bales instead of the traditional method of rock and gravel, we are conserving our natural resources and saving money. In addition, drainage in perpetually troublesome road sections has been greatly improved thus extending the life of the road, reducing the need for constant patching and maintenance, and ensuring a safe ride for the traveling public.

Sheriff's Department

The inmates who participated in the tire baling work program became model prisoners. They came back to the jail with a sense of pride and accomplishment. Incidents of fights, illnesses, and complaints dropped drastically within this group.

CONCLUSION

Chautauqua County Department of Public Facilities, Division of Transportation has successfully devised and implemented an innovative program to clear the landscape of scrap tires at no cost to county residents through the Tire Amnesty Program and to transform these tires into viable road construction materials through baling resulting in substantial savings to the taxpayers of Chautauqua County, safer roadways for the traveling public, and at the same time lessened the risk of the spread of the West Nile Virus by eliminating many potential mosquito breeding areas.

FOR MORE INFORMATION

Please contact:

Kate Hill, Resource Assistant
Chautauqua County
Department of Public Facilities
454 North Work Street
Falconer, NY 14733
(716) 661-8461
(716) 665-4496 (fax)

Comprehensive information package and video available.

Case Study 3: Front Range Tire Recycle, Inc., Sedalia, Colorado

Front Range Tire Recycle, Inc. is a tire recycling facility located in Sedalia, southwest of Denver, Colorado. This facility is located on a property adjacent to a set of railroad tracks. Part of the property that lies nearest the railroad tracks is located on a relatively steep slope. Maximizing the use of the property has always been difficult due to the sloping terrain of the property.

When Front Range Tire Recycle, Inc. opened for business, the method of storing the tires involve simple stockpiling of large quantities of tires. This approach was later deemed unsafe because of the fire hazard posed by the tires as well as because of the breeding ground for infectious mosquitoes. Consequently, Front Range Tire Recycle, Inc. initiated tire shredding operations. Among other reasons, tire shredding decreases the volume of tire stockpiles. However, problems associated with fire hazard are still of concern. In addition to safety issues, the commercial demand for shredded tires was not significant. Recently, the owner of the company decided to manufacture tire bales.

According to the owner of the company, Mr. Rick Welle, more tires can be stored when using tire baling approaches. Also, there seems to be a "good market" for the bales. In addition, Mr. Welle has been utilizing tire bales for road construction within his facility. The road construction activities that took place at this facility are reported herein.

The portion of the property at Front Range Tire Recycle, Inc. that lies adjacent to the railroad tracks was essentially unusable due to the steep grade of the slope. Consequently, in an effort to maximize land usage, the company decided in 2000 to construct a road on top of the slope using tire bales. Such a road would route the truck traffic across the facility.

Construction of the road involved an initial excavation into the slope (i.e. a "cut" excavation), which was conducted to define a relatively flat surface in order to place the tire bales. Next, the tire bales were stacked in a "brick-like" fashion using a forklift. Once the stacked bales reached the desired height for the roadway, the bales were compacted using a front-end loader. In addition to soil, tire shreds were spread over the surface of the tire bale layers in an effort to level the roadway. Finally, soil was placed in uniform layers above the final layer of tire bales and compacted. A view of the road at this Sedalia facility is shown in Figure B3.

Visual inspection of the road indicates that the structure has performed very well so far, with little need for maintenance. The only reported maintenance need involved the repair of some small sinkholes that developed near the edges of the roadway. Figure B4 shows a typical sinkhole. The mechanism for sinkhole generation is attributed to incomplete filling the voids of the tire bales with soil. The sinkholes developed because tire shreds were not initially spread in their vicinity after stacking the bales. Maintenance operations involved filling and compacting the sinkholes with soil (Welle, 2003, personal communication). In spite of the development of few sinkholes, the road has performed extremely well even though it is subjected to daily heavy truck traffic (e.g. semi with trailers) and occasionally large construction equipment (e.g. front-end loaders and scrapers).



Figure B3. Road built from stacked tire bales.

Recent Colorado state laws required that the company divide some of the existing tire and tire shred piles in case of an emergency fire situation. As a result of this regulation, the company has begun to divide a few of his large piles with roadways wide enough for a fire engine to circulate. Because of the successful performance of the first tire bale road, additional roads with tire bales are in the process of being constructed. One of these roads is shown in Figure B5. However, it should be noted that the tire bales that are being

placed are on top of compacted soil that is underlain by another layer of tire bales.

Even though there have been experimental tire bale applications for civil engineering applications, similar to the case studies described above, there exists a need for additional research. Nearly all of the civil engineering projects that have utilized tire bales have been completed on a "trial-and-error" basis. This method has proven itself to be very successful in most cases. However, to fully utilize tire bales and make them available on a large scale for civil engineering applications, research will need to be conducted to further the knowledge of the properties and capabilities of tire bales.



Figure B4. Typical sinkhole.



Figure B5. Roadway construction using tire bales.

APPENDIX C. General Properties of Tires and Results of March 2000 Tire Bale Lab Tests

Materials Composition, Rubber Manufacturer's Association Fact Sheet

**Creep and Load Test on Tire Bale, Twin City Testing /Encore Systems
March 2000**

SCRAP TIRES :: SCRAP TIRE MARKETS

[Scrap Tires and the Environment](#) | [Scrap Tire Markets](#) | [Conferences & Events](#) | [State Issues](#)

[Facts & Figures](#) · [Scrap Tire Characteristics](#)

1. Typical Materials Composition of a Tire
2. Typical Composition by Weight
3. Densities of Shredded and Whole Tires
4. Rubber weight by tire component.
5. Steel Tire Cord Analysis

1. Typical Materials Composition of a Tire

<p>This table lists the typical types of materials used to manufacture tires.</p>
<p>Typical Composition of a Tire</p> <p>Synthetic Rubber</p> <p>Natural Rubber</p> <p>Sulfur and sulfur compounds</p> <p>Silica</p> <p>Phenolic resin</p> <p>Oil: aromatic, naphthenic, paraffinic</p> <p>Fabric: Polyester, Nylon, Etc.</p> <p>Petroleum waxes</p> <p>Pigments: zinc oxide, titanium dioxide, etc.</p> <p>Carbon black</p> <p>Fatty acids</p> <p>Inert materials</p> <p>Steel Wire</p>

2. Typical Composition by Weight

This lists the major classes of materials used to manufacture tires by the percentage of the total weight of the finished tire that material class represents.

Passenger Tire

Natural rubber	14 %
Synthetic rubber	27%
Carbon black	28%
Steel	14 - 15%
Fabric, fillers, accelerators, antiozonants, etc.	16 - 17%
Average weight:	New 25 lbs, Scrap 20 lbs.

Truck Tire

Natural rubber	27 %
Synthetic rubber	14%
Carbon black	28%
Steel	14 - 15%
Fabric, fillers, accelerators, antiozonants, etc.	16 - 17%
Average weight:	New 120 lbs., Scrap 100 lbs.

3. Densities of Shredded and Whole Tires

LOOSELY PACKED	APPROXIMATE DENSITIES	DENSELY PACKED
550-600 lbs/yd ³	single pass	1220-1,300 lbs/yd ³
850-950 lbs/yd ³	2" shred	1,350-1,450 lbs/yd ³
1,000-1,100 lbs/yd ³	1 1/2" shred	1,500-1,600 lbs/yd ³
100/10Yd ³	WHOLE TIRES (PASSENGER/LIGHT TRUCK)	500/10Yd ³
	10 MESH- 29 lbs/ft ³	
	20 MESH- 28 lbs/ft ³	
	30 MESH- 28 lbs/ft ³	
	40 MESH- 27 lbs/ft ³	
	80 MESH- 25-26 lbs/ft ³	

4. Rubber weight by tire component.

A tire is manufactured from several separate components, such as tread, innerliner, beads, belts, etc. This table shows which components account for the rubber used to make the tire.

RUBBER PERCENT BY WEIGHT IN A NEW RADIAL PASSENGER TIRE

TREAD	32.6%
BASE	1.7%
SIDEWALL	21.9%
BEAD APEX	5.0%
BEAD INSULATION	1.2%
FABRIC INSULATION	11.8%
INSULATION OF STEEL CORD	9.5%
INNERLINER	12.4%
UNDERCUSHION	3.9%
	<hr/> 100.0%

5. Steel Tire Cord Analysis

The tire industry uses ASTM 1070 and above tire cord quality wire rod in the manufacture of new tires. There are approximately 100 pounds of steel belts and bead wire in a passenger car tire.

662 Cromwell Avenue, St. Paul, MN 55114-1776
(651) 645-3601, Fax: (651) 659-7348**TO:** Mr. Ed Drews
Encore Systems, Inc.
585 Northwest 3rd
Cohasset, MN 55721**DATE:** March 24, 2000**PROJECT NO:** 030066**PROJECT:** MNDOT TEST OF TIRE BAIL

CREEP AND LOAD TEST ON TIRE BAIL**INTRODUCTION:**

This report presents the results of load testing performed by Stork Twin City Testing Corporation (TCT), on one tire bail submitted by the Encore Systems of Cohasset, Minnesota. The scope of our work was limited to:

1. Performing a creep test on the tire bail.
2. Performing a load deflection test on the tire bail.
3. Presenting a report of our test results.

Our work was requested and authorized by Mr. Ed Drews of the Encore Systems on March 2, and March 7, 2000, respectfully.

SUMMARY OF TEST RESULTS:

<u>Type of Test</u>	<u>Maximum Load</u>	<u>Avg. Ultimate Deflection, inch.</u>	<u>Time of ultimate Deflection, If applicable</u>
Creep	88,000 Lbs.	8.06	4320 min (72 hours)
Load Deflection	338,850 Lbs.	11.45	N/A

SAMPLE DESCRIPTION:

On March 15, 2000, one tire bail was submitted to TCT for load testing. The test bail was approximately 60 inches in length by 50 inches in width and 30 inches in height. The test bail consisted of tires compacted with steel wire. The bail came with a steel plate on top that measured 60 inches in length by 50 inches in width and 1 inch thick.

TEST PROCEDURES:

Laboratory testing was performed March 17, 2000 and subsequent dates. A summary of test procedures is as follows:

1. The test bail, with the steel plate on top, was placed under a stationary reaction frame within our laboratory on a steel plate. We then placed a number of beams across the steel test plate to distribute the load during testing.

CREEP AND LOAD TEST ON TIRE BAIL**TEST PROCEDURES:** (cont.)

2. A hydraulic ram, connected to a hand (creep test) or electric (load deflection test) pump, was placed on the steel beams and below the reaction frame. A hydraulic gauge was used to monitor the load during test. The hydraulic pump and ram system calibration was traceable to the National Institute of Standards and Technology.
3. The creep test was performed first. A load of 88,000 pounds was applied to the bail and held.
4. Deflection readings were the obtained using a tape measure. The measurements were taken from the floor to the top plate at all four corners. The load was held until no noticeable deflection increase was observed. The load was then released.
5. The load deflection test was then performed using the same test configuration.
6. The sample was loaded in equal increments, to a load of approximately 335,000 pounds. At each load increment deflection readings were obtained in a similar fashion as the creep test.
7. Upon loading 335,000 pounds, the load was released and the sample was inspected for distress.

TEST RESULTS:**Creep Test**

<u>Time (min.)</u>	<u>Average Deflection (inches)</u>
0	0
5	6.02
10	5.98
15	6.64
20	6.78
25	6.78
30	6.94
35	7.00
40	7.05
45	7.03
50	7.03
55	7.05
60	7.22
120	7.22
180	7.30
240	7.44
300	7.55

PROJECT NO: 030066

DATE:
PAGE:

March 24, 2000
3

CREEP AND LOAD TEST ON TIRE BAIL

TEST RESULTS: (Cont.)

Creep Test (Cont.)

<u>Time (min.)</u>	<u>Average Deflection (inches)</u>
1620	7.55
2820	8.02
4320	8.06

The load remained constant at 88,000 pounds.

Load Deflection Test

<u>Load (Lbs.)</u>	<u>Average Deflections (inches)</u>
0	0
55,450	4.25
103,600	6.95
150,800*	8.95
199,250	9.70
246,450	10.70
292,250	11.20
338,950	11.45

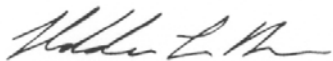
*A bundle strap failed at approximately 175,000 pounds.

Please see the attached photographs and graphs.

REMARKS:

Unless further notice is received, the sample will be retain for a period of two weeks and then discarded. If you have any questions regarding this report, or if we may be of further assistance, please feel free to contact us at (651) 659-7340.

STORK TWIN CITY TESTING CORPORATION



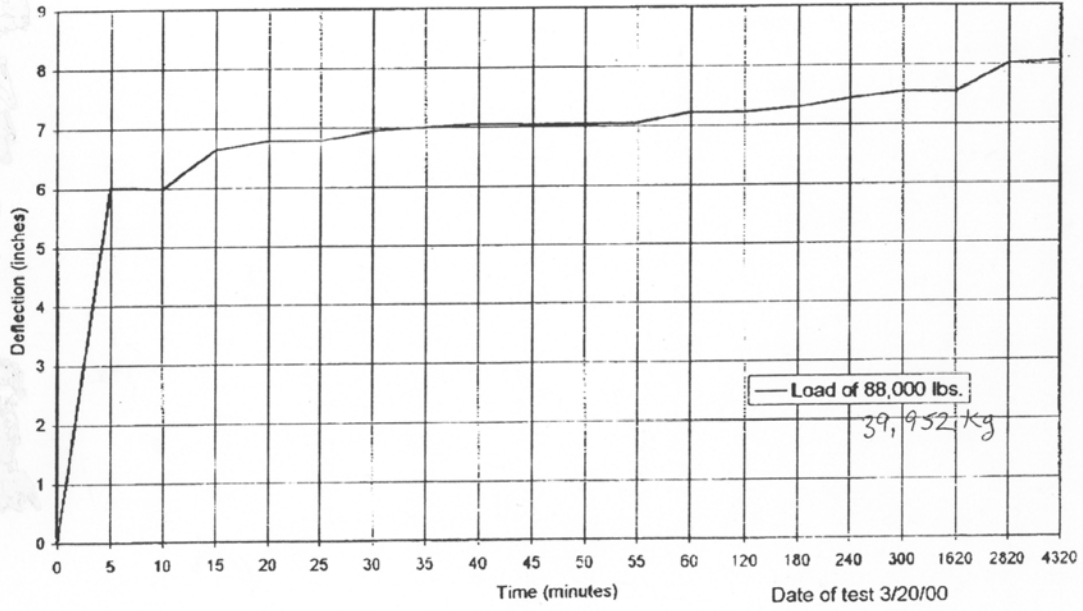
Thaddeaus L. Harnois
Staff Engineer
Construction Materials Department
\\TWINCITIES_NW5\SYSTEMS\BMC\2000CME\030066\Report.doc



John D. Lee, P.E.
Senior Staff Engineer
Construction Materials Department



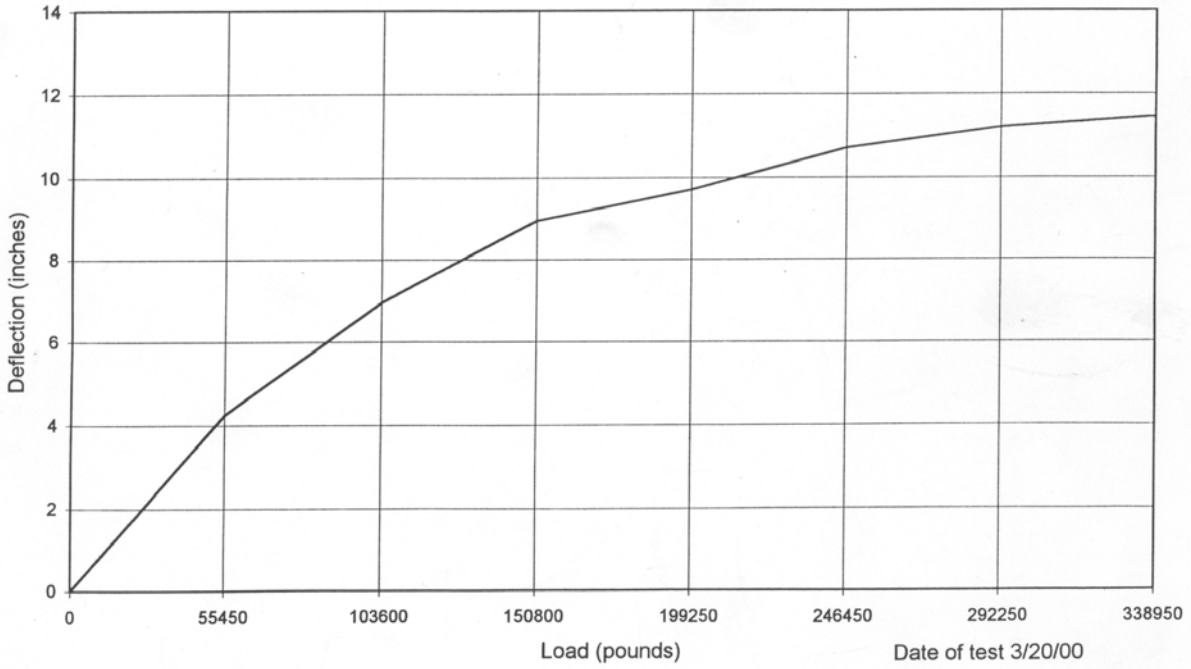
CREEP TEST (Deflection vs. Time)
ENCORE SYSTEMS
Project No. 03-0066





LOAD DEFLECTION TEST
ENCORE SYSTEMS
Project No. 03-0066

STORK®



APPENDIX D. 2004 Lab Test Data on Tire Bales (performed for this study)



Subject: **Summary of the Laboratory Tests Performed for the Tire Bale Study**
 GTX Project No.: G0581
 December 16, 2004

GeoTesting Express, Inc. (GTX) has completed the laboratory tests on tire bales received in accordance with the scope of work and GTX proposal No. 0050197. The following sections briefly describe the test performed including any modifications made during the performance of the test program as was previously discussed in our interim reports. The test results from all tests performed follow the description of the test program.

TIRE BALE LABORATORY TEST PROGRAM

The following laboratory test program was performed on the (9) tire bales that were received at the GeoTesting Express, Inc. laboratory in Alpharetta, GA. All tests were performed on the entire bale. The tire bales will have a rough estimated size of 2.5 ft x 4.5 ft x 5 ft and weigh approximately 1 ton. The sequence and procedures listed below were followed to allow for reuse of bales where possible.

- **Dry, wet and submerged unit weight of as received tire bales.**

Unit weigh tests were made on all samples received. The procedure consisted of volumetric measurements and weight of the sample as received noting any presence of moisture in the bale. The volume was measured by taking dimensional measurements. For dimensional measurements, a significant number of measurements were taken to obtain unit weight measurements within a 1 % accuracy and repeatability. Digital image analysis was used to confirm the measurements with two digital photos (front and side view) taken of each bale along with a visible reference scale mounted on the bale using a level camera located vertically at the mid height of the bale. Representative images are shown included with this report. At least two bales were stored in a dry environment for a sufficient period of time (i.e., no weight change within a 1 day period of time) in order to obtain an air dry unit weight for these two samples. These two samples were then also used to obtain the submerged and wet unit weight of the tire bales.

Submerged unit weight measurements were obtained by submerging the entire bale in a tank of water for a sufficient period of time to allow all free air to escape and obtain the weight below water. Prior to placement in the tank, the water in the tank was maintained at room temperature for at least 24 hours to reduce the amount and equilibrate the dissolved oxygen in the water. After obtaining the submerged weight, each sample was extracted from the water, allowed to freely drain, and weighed immediately after drainage to obtain the wet unit weight.

– **Vertical Permeability of tire bales.**

- The vertical permeability of two (2) tire bales was evaluated by rapidly extracting the bale which had been submerged in water and monitoring the time it takes for water to completely drain from the sample under gravity flow. The horizontal sides of the tire bale were wrapped with shrink wrap to prevent lateral flow out of the sides of the bale. The time of extraction was sufficiently rapid to maintain a visible and measurable differential head differential (e.g., with piezometers) between the water in the reservoir and in the sample.

– **Unconfined compressibility with both vertical and horizontal deformation measurements.**

- Unconfined compression tests were performed generally following the ASTM D2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. These tests were performed at the Georgia Institute of Technology structural laboratory in Atlanta, Georgia and a separate report is attached on this phase of the testing program. In summary, the top and bottom loading platens consisted of large concrete blocks, which had surface area that was greater than the compressed loaded tire bale surface area and extended beyond the dimensions of the sample in all directions when fully loaded. The load platens were also sufficiently stiff so as not to bend or deform during testing and distribute the load uniformly across the sample. A minimum of three vertical deformation measurements (to an accuracy of 0.1 inches) was made with gages located equal distances around the sample (e.g., 3 gages located at the third points around the sample). Lateral movement was also measured in at least three equally spaced (from top to bottom) vertical locations by measuring the circumference with a tape measure. A calibrated load cell was used to measure the applied load. A peak strength was not reached for the tire bales and tests were performed to maximum loads of 300 to 600 kips, based on equipment compatibility and safety. Both continuous monitoring using data acquisition methods and manual readings to perform a check were made, with vertical and horizontal deformation shall be taken at a minimum of every 10 kips up to 100 kips and at every 25 kips up to the full load condition. An unload – reload test was performed on one of the bales.

- **Unconfined and confined compressibility of tire bales (i.e., without and with in fill materials) at working loads, including static and cyclic modulus evaluation.**

These tests were performed in the GeoTesting Express, Inc. laboratory in a similar manner as the unconfined tests except that the maximum load was 20 kips, steel platens with an area greater than the compressed tire bale were used to apply the load, and the cyclic load was performed at 9 kips with a one foot circular plate (to simulate a vehicle load at the tire surface). Two tests were performed on two separate tire bale samples, one unconfined and one confined with a minimum of six inches of dry, concrete sand (ASTM C-33) completely surrounding the sides of the tire bale. For the confined test, the samples were contained in a rigid box, the sand placed in the annulus between the sides of the box and the sample, and the surface sand was compacted with a vibratory plate compactor a minimum of five passes. Sand that subsided during compaction was replaced to form a level surface. For the cyclic load test a level bearing surface was provided beneath the circular plate using a non shrink mortar mix. Prior to performing the static compression test on either of the unconfined or confined tire bale, the cyclic load test was performed using a 1 ± 0.5 hertz frequency for a minimum of 1000 cycles. Vertical deformation measurements (to an accuracy of 0.001 inches) were made using LVDT's and a data acquisition system. Following the cyclic load test, the static load deformation test was performed to 20 kips.

- **Time-dependent deformations of tire bales under sustained load (i.e. creep).**

Creep test consisted of placing a constant load on a single unconfined tire bale and monitoring the deformation response for a period of 1000 hrs at a constant room temperature. Three tests were performed fresh bales (previously not used in the test program), one with an applied load of 8 kips and the other two with an applied load of 20 kips. In this case, metal plates with an area greater than the compressed tire bale were used for the load platens and an air bag was used to sustain the required load. Twin air bags were used to sustain the required load. A second steel plate was placed above the air bags, and a load cell was placed between the upper steel plate and a reaction beam to monitor the applied stress. The vertical deformation measurements were made using three gages, with an accuracy of 0.0254 mm (0.001 in.) placed evenly (at the third points) around the sample. The first 90 kN (20 kips) test experienced accelerated movement on one corner after approximately 190 hrs and the test had to be terminated. There is a tendency for tires to shift laterally in their unconfined condition. The second 90 kN (20 kips) did not experience this problem and the test was performed to the required 1000 hrs of time.

- **Shear strength between adjacent vertically stacked tire bales.**

In this test, a direct shear test was performed by vertically stacking two tire bales, restraining the upper bale from moving laterally, and measuring the force to pull out the bottom bale, which was supported by low friction rollers. The air bag system used in the creep tests was used to apply the normal load. Tests were conducted at normal loads of 9 kN (2 kips) (i.e., the dead weight of the upper bale), 18 kN (4 kips), and 27 kN (6 kips).

During application of shear force the bales tended to roll due to interlocking at undulations on the interface surfaces, rather than slide along the interface. This resulted in eccentric loading on the load cell used to monitor the normal stress and the test had to be stopped before a peak shear stress could be reached.

– **Rebound and potential expansive pressure.**

In order to evaluate uplift potential, two tests were performed, one to evaluate swell pressure plus free swell and the other to evaluate free swell alone. The first test was conducted on a sample that had been manufactured and stored for a period of 1 year. In this test, a rigid piston with a load cell was placed on the sample using a wooden pallet as a platen to facilitate cutting of the wires. The five vertical tie wires were then cut and the load required to prevent any upward vertical movement was measured. The load to prevent uplift was relatively small and stabilized within an hour at 1.6 kN (356 lbs). However, after cutting of the wires, significant lateral movement was observed and continued after the load had stabilized. After no increase in upward pressure was observed, the load was released and the upward vertical movement was monitored until no additional movement occurred. A relatively small average vertical movement of 21.4 mm (1 in.) was measured. The lateral movement was significant with almost 600 mm (2 ft) of movement observed in the band width direction [300 mm (1 ft) on each side], until the bale was restrained by the sides of the 2 m wide (6.6 ft) container.

Due to the significant lateral movement observed during the first test, the second test was performed by restraining the lateral movement with several lifting straps, simulating confinement by adjacent tire bales. All five vertical tie wires on a tire bale were cut and the upward vertical movement monitored.

The following test matrix was used in order to maximize the number of test that could be performed on the nine (9) tire bales.

Table 1. Tire Bale Test Matrix

Sample Number	Unit Weight	k	UC-ult	UC-conf. & cyclic	Shear (τ)	Swell rebound & Press.	Creep
1	X	X		X	X		X
2	X	X		X	X		X
3	X				X	X	
4	X					X	
5	X		X				
6	X		X				
7	X		X				
8	X		X				
9 - Old	X					X	

Representative Photos of Tire Bales used for Lab Tests

Tire Bale 0,
Side 1



Tire Bale 0,
Side 2



Tire Bale 5,
Side 1



Tire Bale 5,
Side 2





GEOMETRY, DRY, WET AND SUBMERGED UNIT WEIGHT

Project No. : GTX G0581
Tested By: SD
Test Date: 4/5/2004

Project Name: Tire Bale Study
Reviewed By: JW
Review Date: 4/9/2004

Tare Weight, lbs:	23
-------------------	----

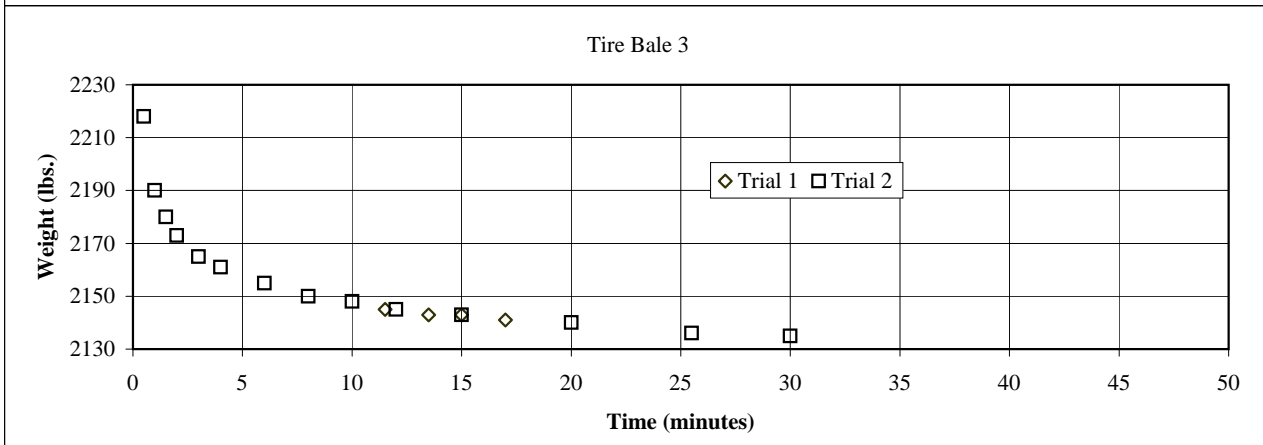
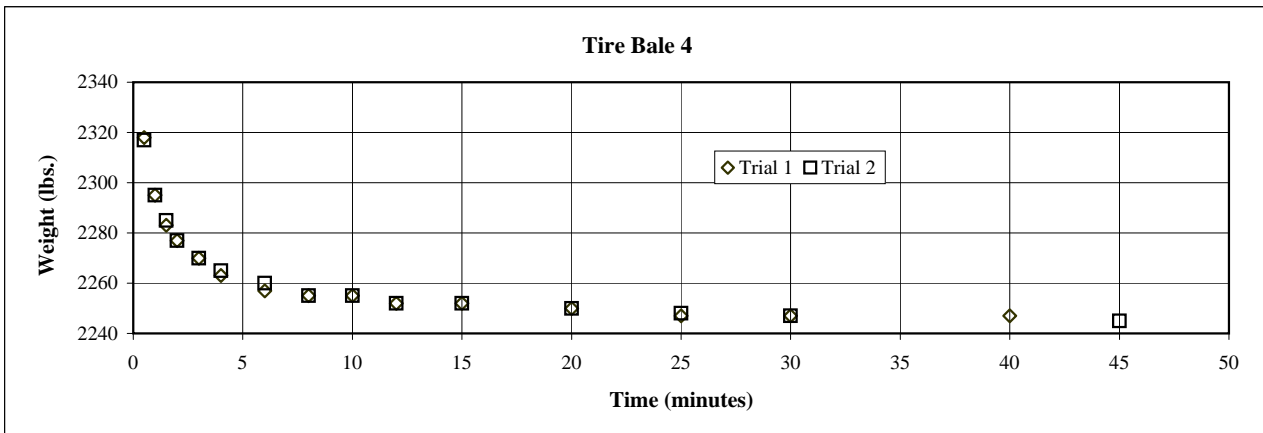
Tire Baled No.	0	3	4	5	6
As Received + Tare Weight, lbs	2185	1933	2073	2026	1998
As Received Weight, lbs	2162	1910	2050	2003	1975
Dry Weight, lbs	2161	1910	2049		
Submerged Weight, lbs	293	189	238		
Wet(Drained) Weight, lbs	2288	2098	2205		
Thickness, ft	2.4	2.3	2.3	2.2	2.4
Width (band direction), ft	4.7	4.7	4.8	4.8	4.8
Width (cross-band direction), ft	5.2	5.0	5.0	5.2	5.3
Volume, ft ³	59.0	54.1	54.4	54.4	59.2
As received Unit Weight, lbs/ft ³	36.6	35.3	37.7	36.8	33.4
Dry Unit Weight:	36.6	35.3	37.7		
Submerged Unit Weight:	5.0	3.5	4.4		
Wet Unit Weight:	38.8	38.8	40.5		

VERTICAL PERMEABILITY OF TIRE BALES

Project No. : GTX G0581
 Tested By: SD
 Test Date: 4/12/2004

Project Name: Tire Bale Study
 Reviewed By: JW
 Review Date: 4/16/2004

Tire Bale 4		Tire Bale 3		Tire Bale 4		Tire Bale 3	
Trial 1		Trial 2		Trial 1		Trial 2	
Time (minutes)	Weight of Tire Bale (lbs)	Time (minutes)	Weight of Tire Bale (lbs)	Time (minutes)	Weight of Tire Bale (lbs)	Time (minutes)	Weight of Tire Bale (lbs)
0.5	2318	0.5	2317	11.5	2145	0.5	2218
1	2295	1	2295	13.5	2143	1	2190
1.5	2283	1.5	2285	15	2143	1.5	2180
2	2277	2	2277	17	2141	2	2173
3	2270	3	2270			3	2165
4	2263	4	2265			4	2161
6	2257	6	2260			6	2155
8	2255	8	2255			8	2150
10	2255	10	2255			10	2148
12	2252	12	2252			12	2145
15	2252	15	2252			15	2143
20	2250	20	2250			20	2140
25	2247	25	2248			25.5	2136
30	2247	30	2247			30	2135
40	2247	45	2245				



Tire Bale 4 - Unconfined
Peak Values
Representative Data

Up to row 1310 Up to column CF

Cycle #	Gen. Def.	LC (kPa)	LC (psi)	LC (lbf)	SD3 (mm)	SD4 (mm)	SD5 (mm)
1	23.78689667	527.483	76.502	8652.200	23.65999	24.30027	23.40043
2	24.21059667	526.822	76.406	8641.358	24.10309	24.71157	23.81713
3	24.29583	522.19	75.735	8565.380	24.18019	24.81437	23.89293
4	24.34129667	520.205	75.447	8532.821	24.21869	24.85547	23.94973
5	24.34129667	517.558	75.063	8489.403	24.21869	24.85547	23.94973
6	24.44563	518.22	75.159	8500.261	24.31509	24.95837	24.06343
7	24.24336333	510.941	74.103	8380.865	24.12239	24.75267	23.85503
8	24.25613	508.295	73.719	8337.463	24.14169	24.75267	23.87403
9	24.21693	504.986	73.239	8283.187	24.10309	24.71157	23.83613
10	24.14543	502.34	72.856	8239.785	24.02609	24.64987	23.76033
11	24.06019667	499.031	72.376	8185.508	23.94899	24.54707	23.68453
12	24.10623	497.046	72.088	8152.948	23.98749	24.60877	23.72243
13	24.11209667	494.4	71.704	8109.546	24.00679	24.58817	23.74133
14	24.07296333	491.091	71.224	8055.270	23.96829	24.54707	23.70353
15	24.02013	487.783	70.744	8001.009	23.94899	24.46477	23.64663
16	24.04606333	485.136	70.361	7957.591	23.96829	24.48537	23.68453
17	24.00686333	483.151	70.073	7925.031	23.92969	24.44427	23.64663
18	23.95396333	480.505	69.689	7881.629	23.89119	24.36197	23.60873
19	23.88876333	477.858	69.305	7838.211	23.81409	24.30027	23.55193
20	23.92169667	476.535	69.113	7816.510	23.85269	24.34147	23.57093
21	23.69343	473.888	68.729	7773.092	23.62149	24.11527	23.34353
22	23.69983	471.903	68.441	7740.533	23.64069	24.11527	23.34353
23	23.70606333	471.241	68.345	7729.674	23.62149	24.11527	23.38143
24	23.50379667	467.933	67.866	7675.413	23.42879	23.90957	23.17303
25	23.41226333	465.948	67.578	7642.854	23.35169	23.80677	23.07833
26	23.41913	465.286	67.482	7631.995	23.35169	23.82737	23.07833
27	23.21639667	461.316	66.906	7566.876	23.15909	23.60117	22.88893
28	23.17719667	460.655	66.810	7556.034	23.12049	23.56007	22.85103
29	23.10566333	458.67	66.522	7523.474	23.04339	23.49837	22.77523
30	22.96209667	456.685	66.234	7490.915	22.88929	23.35437	22.64263
31	22.89016333	455.361	66.042	7469.197	22.83149	23.27217	22.56683
32	22.81866333	453.376	65.754	7436.638	22.75439	23.21047	22.49113
33	22.74029667	452.053	65.562	7414.937	22.67739	23.12817	22.41533
34	22.64233	450.73	65.371	7393.236	22.58099	23.02537	22.32063
35	22.54479667	448.745	65.083	7360.676	22.46539	22.94317	22.22583
36	22.49879667	447.421	64.891	7338.959	22.42689	22.88147	22.18803
37	22.40083	445.436	64.603	7306.400	22.33059	22.77867	22.09323
38	22.36163	444.113	64.411	7284.699	22.29199	22.73757	22.05533
39	22.29016333	443.451	64.315	7273.840	22.21499	22.67587	21.97963
40	22.42039667	444.775	64.507	7295.557	22.34979	22.79917	22.11223
41	22.59673	449.406	65.179	7371.519	22.52319	22.98427	22.28273
42	22.66823	451.391	65.466	7404.078	22.60029	23.04597	22.35843
43	22.80539667	454.038	65.850	7447.496	22.73519	23.18987	22.49113
44	22.94253	456.023	66.138	7480.056	22.86999	23.33387	22.62373
45	23.09926333	459.331	66.618	7534.316	23.02419	23.49837	22.77523
46	23.17076333	461.316	66.906	7566.876	23.10119	23.56007	22.85103
47	23.26229667	462.64	67.098	7588.593	23.17829	23.66287	22.94573
48	23.52973	465.948	67.578	7642.854	23.44809	23.93017	23.21093
49	23.60809667	468.595	67.962	7686.272	23.52509	24.01247	23.28673
50	23.76483	469.918	68.153	7707.973	23.67929	24.17697	23.43823
51	23.84316333	471.903	68.441	7740.533	23.75629	24.25917	23.51403
52	24.03226333	475.211	68.921	7794.793	23.94899	24.44427	23.70353
53	24.12333	476.535	69.113	7816.510	24.04529	24.52647	23.79823
954	28.20746333	466.61	67.674	7653.713	28.22629	28.39237	28.00373
955	28.10323	465.286	67.482	7631.995	28.12999	28.28957	27.89013
956	27.97923	462.64	67.098	7588.593	27.99509	28.16617	27.77643
957	27.91359667	460.655	66.810	7556.034	27.93729	28.08387	27.71963

Peak

958	27.79606333	458.67	66.522	7523.474	27.82169	27.96057	27.60593
959	27.69853	456.023	66.138	7480.056	27.70609	27.87827	27.51123
960	27.58736333	454.7	65.946	7458.355	27.60969	27.75487	27.39753
961	27.51536333	452.715	65.658	7425.796	27.53269	27.67267	27.34073
962	27.42423	451.391	65.466	7404.078	27.43629	27.59037	27.24603
963	27.30036333	448.083	64.987	7349.818	27.32069	27.46697	27.11343
964	27.20239667	446.76	64.795	7328.117	27.22439	27.36417	27.01863
965	27.05886333	444.113	64.411	7284.699	27.07029	27.22027	26.88603
966	26.98059667	442.128	64.123	7252.139	27.01249	27.13797	26.79133
967	26.88893	440.143	63.835	7219.579	26.91609	27.03517	26.71553
968	26.81063	438.819	63.643	7197.862	26.83909	26.95297	26.63983
969	26.58236333	432.864	62.779	7100.183	26.60789	26.72677	26.41243
970	26.60193	434.849	63.067	7132.743	26.62709	26.74727	26.43143
971	26.39329667	429.556	62.300	7045.923	26.41519	26.54167	26.22303
972	26.47809667	432.864	62.779	7100.183	26.51149	26.62397	26.29883
973	26.52359667	434.188	62.971	7121.901	26.55009	26.66507	26.35563
974	26.58876333	435.511	63.163	7143.602	26.62709	26.72677	26.41243
975	26.77826333	440.804	63.931	7230.422	26.80049	26.93237	26.60193
976	26.88263	442.789	64.219	7262.981	26.91609	27.03517	26.69663
977	26.92813	444.113	64.411	7284.699	26.95469	27.07627	26.75343
978	26.98693	444.775	64.507	7295.557	27.01249	27.13797	26.81033
979	27.12406333	448.745	65.083	7360.676	27.14729	27.28197	26.94293
980	27.23473	450.73	65.371	7393.236	27.26289	27.38477	27.05653
981	27.33269667	452.715	65.658	7425.796	27.35929	27.48757	27.15123
982	27.43709667	455.361	66.042	7469.197	27.47489	27.59037	27.24603
983	27.56139667	458.008	66.426	7512.616	27.57119	27.73437	27.37863
984	27.63926333	459.331	66.618	7534.316	27.66749	27.79597	27.45433
985	27.75686333	462.64	67.098	7588.593	27.78319	27.91937	27.56803
986	27.82883	464.625	67.386	7621.153	27.84099	28.00167	27.64383
987	27.93319667	465.948	67.578	7642.854	27.95659	28.10447	27.73853
988	28.01796333	468.595	67.962	7686.272	28.05289	28.18667	27.81433
989	28.12276333	469.918	68.153	7707.973	28.14919	28.31007	27.90903
990	28.22706333	473.226	68.633	7762.233	28.24559	28.41287	28.02273
991	28.21429667	472.565	68.537	7751.391	28.22629	28.41287	28.00373
992	28.35099667	475.873	69.017	7805.652	28.38039	28.53627	28.13633
993	28.41666333	476.535	69.113	7816.510	28.43819	28.61857	28.19323
994	28.56716333	480.505	69.689	7881.629	28.61159	28.78307	28.30683
995	28.56029667	479.843	69.593	7870.771	28.61159	28.76247	28.30683
996	28.59373	481.166	69.785	7892.472	28.65019	28.82417	28.30683
997	28.66653	483.813	70.169	7935.890	28.76579	28.92697	28.30683
998	28.73289667	486.46	70.553	7979.308	28.86209	29.02977	28.30683
999	28.77273	487.121	70.648	7990.150	28.91989	29.09147	28.30683
1000	28.78603	487.121	70.648	7990.150	28.93919	29.11207	28.30683
1001	28.87893	490.43	71.128	8044.427	29.07399	29.25597	28.30683
1002	28.92519667	492.415	71.416	8076.987	29.15109	29.31767	28.30683
1003	28.96503	493.076	71.512	8087.829	29.20889	29.37937	28.30683
1004	29.01119667	494.4	71.704	8109.546	29.26669	29.44107	28.32583
1005	29.09779667	497.708	72.184	8163.807	29.40159	29.58497	28.30683
1006	29.14449667	499.031	72.376	8185.508	29.45939	29.66727	28.30683
1007	29.19076333	500.355	72.568	8207.225	29.53649	29.72897	28.30683
1008	29.23699667	501.678	72.760	8228.926	29.61349	29.79067	28.30683
1009	29.30339667	503.663	73.048	8261.486	29.70989	29.89347	28.30683
1010	29.26356333	502.34	72.856	8239.785	29.65209	29.83177	28.30683

**Tire Bale 4 - Unconfined
Minimum Values**

Under a Cyclic Load of 9 kips

Cycle #	Cen. Def.	Representative Data						
		LC (kPa)	LC (psi)	LC (lbf)	SD3 (mm)	SD4 (mm)	SD5 (mm)	
1	0	10.5536	1.531	173.109	0	0	0	
2	0.917206667	10.0574	1.459	164.970	0.90074	0.95104	0.89984	
3	1.20604	10.0574	1.459	164.970	1.18493	1.2492	1.18399	
4	1.373873333	9.89196	1.435	162.256	1.3487	1.4137	1.35922	
5	1.497816667	10.0574	1.459	164.970	1.47875	1.53708	1.47762	
6	1.594223333	10.2228	1.483	167.683	1.5799	1.6399	1.56287	
7	1.665953333	9.89196	1.435	162.256	1.64734	1.71187	1.63865	
8	1.72459	10.0574	1.459	164.970	1.70514	1.76842	1.70021	
9	1.783363333	9.89196	1.435	162.256	1.76294	1.83011	1.75704	
10	1.830653333	9.72655	1.411	159.543	1.81592	1.87637	1.79967	
11	1.861596667	9.56113	1.387	156.829	1.84001	1.90722	1.83756	
12	1.920286667	9.72655	1.411	159.543	1.90744	1.96377	1.88965	
13	1.962733333	9.89196	1.435	162.256	1.94116	2.01003	1.93701	
14	1.998623333	9.56113	1.387	156.829	1.97969	2.04602	1.97016	
15	2.034353333	9.56113	1.387	156.829	2.01341	2.07686	2.01279	
16	2.0734	9.56113	1.387	156.829	2.05194	2.11285	2.05541	
17	2.094596667	9.72655	1.411	159.543	2.07603	2.13341	2.07435	
18	2.120773333	9.72655	1.411	159.543	2.0953	2.16425	2.10277	
19	2.143576667	9.56113	1.387	156.829	2.1242	2.18482	2.12171	
20	2.169643333	9.56113	1.387	156.829	2.14828	2.21052	2.15013	
21	2.1891	9.56113	1.387	156.829	2.16755	2.22594	2.17381	
22	2.20869	9.72655	1.411	159.543	2.18681	2.24651	2.19275	
23	2.22325	9.72655	1.411	159.543	2.20126	2.25679	2.2117	
24	2.23952	9.56113	1.387	156.829	2.21571	2.27221	2.23064	
25	2.250976667	9.39571	1.363	154.116	2.2398	2.28249	2.23064	
26	2.26559	9.56113	1.387	156.829	2.2398	2.29791	2.25906	
27	2.283493333	9.56113	1.387	156.829	2.26388	2.31334	2.27326	
28	2.284966667	9.56113	1.387	156.829	2.2687	2.3082	2.278	
29	2.29155	9.39571	1.363	154.116	2.2687	2.31848	2.28747	
30	2.306216667	9.56113	1.387	156.829	2.27833	2.3339	2.30642	
31	2.312746667	9.56113	1.387	156.829	2.29278	2.33904	2.30642	
32	2.322513333	9.39571	1.363	154.116	2.2976	2.34932	2.32062	
33	2.327413333	9.72655	1.411	159.543	2.30242	2.35446	2.32536	
34	2.334023333	9.39571	1.363	154.116	2.30723	2.36474	2.3301	
35	2.3405	9.39571	1.363	154.116	2.31205	2.36988	2.33957	
36	2.343573333	9.2303	1.339	151.403	2.32168	2.36474	2.3443	
37	2.350186667	9.2303	1.339	151.403	2.3265	2.37502	2.34904	
38	2.353483333	9.56113	1.387	156.829	2.3265	2.38017	2.35378	
39	2.361696667	9.2303	1.339	151.403	2.33613	2.39045	2.35851	
40	2.366433333	9.39571	1.363	154.116	2.33613	2.39045	2.37272	
41	2.3777	9.2303	1.339	151.403	2.35058	2.39559	2.38693	
42	2.39084	9.39571	1.363	154.116	2.36985	2.41101	2.39166	
43	2.40722	9.39571	1.363	154.116	2.37948	2.43157	2.41061	
44	2.423603333	9.72655	1.411	159.543	2.38912	2.45214	2.42955	
45	2.43819	9.39571	1.363	154.116	2.40839	2.46242	2.44376	
46	2.45767	9.56113	1.387	156.829	2.43247	2.47784	2.4627	
47	2.46771	9.56113	1.387	156.829	2.43729	2.4984	2.46744	
48	2.48224	9.72655	1.411	159.543	2.44692	2.50868	2.49112	
49	2.50515	9.56113	1.387	156.829	2.471	2.53439	2.51006	
50	2.519843333	9.39571	1.363	154.116	2.48545	2.54981	2.52427	
51	2.5344	9.89196	1.435	162.256	2.4999	2.56009	2.54321	
52	2.5556	9.56113	1.387	156.829	2.52399	2.58065	2.56216	
53	2.586566667	9.56113	1.387	156.829	2.55289	2.6115	2.59531	
54	2.606156667	9.72655	1.411	159.543	2.57216	2.63206	2.61425	
55	2.620716667	9.56113	1.387	156.829	2.58661	2.64234	2.6332	
56	2.645313333	9.56113	1.387	156.829	2.60587	2.67319	2.65688	
57	2.664796667	9.72655	1.411	159.543	2.62996	2.68861	2.67582	
58	2.684496667	9.56113	1.387	156.829	2.64441	2.71431	2.69477	
59	2.70727	9.72655	1.411	159.543	2.66849	2.73488	2.71844	
60	2.731626667	9.72655	1.411	159.543	2.69258	2.75544	2.74686	
61	2.754236667	9.72655	1.411	159.543	2.71184	2.77086	2.78001	
62	2.772386667	9.72655	1.411	159.543	2.73111	2.79657	2.78948	
63	2.808386667	9.72655	1.411	159.543	2.76483	2.83769	2.82264	
64	2.824656667	9.72655	1.411	159.543	2.77928	2.85311	2.84158	
65	2.853936667	9.89196	1.435	162.256	2.81299	2.87882	2.87	
66	2.866863333	9.72655	1.411	159.543	2.81781	2.8891	2.89368	
67	2.892956667	9.72655	1.411	159.543	2.84671	2.9148	2.91736	
68	2.920873333	9.89196	1.435	162.256	2.8708	2.95079	2.94103	
69	2.950126667	9.89196	1.435	162.256	2.8997	2.97649	2.97419	
70	2.97132	9.72655	1.411	159.543	2.92378	2.99705	2.99313	
71	3.005473333	9.89196	1.435	162.256	2.9575	3.0279	3.03102	
72	3.033116667	9.89196	1.435	162.256	2.98158	3.0536	3.06417	
73	3.06596	9.72655	1.411	159.543	3.0153	3.09473	3.08785	
74	3.091783333	9.72655	1.411	159.543	3.0442	3.11015	3.121	
75	3.109906667	9.89196	1.435	162.256	3.05865	3.13586	3.13521	
76	3.147236667	9.89196	1.435	162.256	3.09718	3.1667	3.17783	
77	3.179943333	9.89196	1.435	162.256	3.1309	3.20268	3.20625	
78	3.212623333	9.89196	1.435	162.256	3.1598	3.23867	3.2394	
79	3.245223333	9.72655	1.411	159.543	3.19834	3.26951	3.26782	
80	3.273003333	10.0574	1.459	164.970	3.22242	3.30036	3.29623	
81	3.298963333	9.89196	1.435	162.256	3.25132	3.32092	3.32465	
82	3.336543333	9.89196	1.435	162.256	3.28504	3.36205	3.36254	
83	3.359236667	9.89196	1.435	162.256	3.31876	3.37747	3.38148	

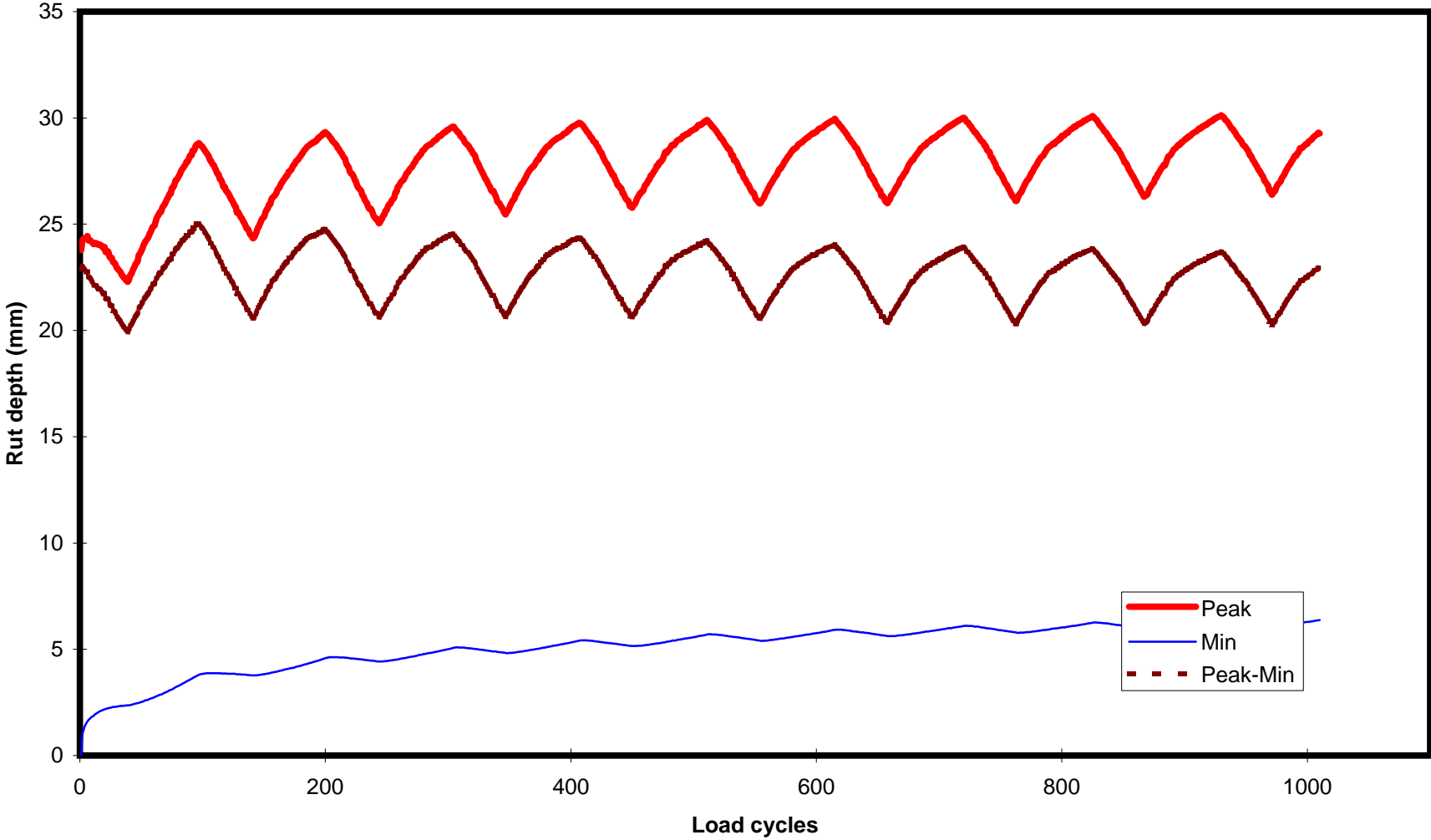
84	3.393603333	10.0574	1.459	164.970	3.34284	3.4186	3.41937
85	3.42446	9.89196	1.435	162.256	3.37656	3.4443	3.45252
86	3.452266667	9.89196	1.435	162.256	3.40546	3.47514	3.4762
87	3.48152	9.89196	1.435	162.256	3.43436	3.50085	3.50935
88	3.520456667	9.89196	1.435	162.256	3.47771	3.53169	3.55197
89	3.54013	9.72655	1.411	159.543	3.48734	3.5574	3.57565
90	3.587446667	10.0574	1.459	164.970	3.54514	3.60366	3.61354
91	3.61349	9.72655	1.411	159.543	3.56441	3.62937	3.64669
92	3.639583333	9.89196	1.435	162.256	3.59331	3.65507	3.67037
93	3.68024	10.2228	1.483	167.683	3.63666	3.69106	3.713
94	3.70655	10.0574	1.459	164.970	3.65593	3.72704	3.73668
95	3.730823333	9.72655	1.411	159.543	3.68965	3.74246	3.76036
96	3.768263333	9.89196	1.435	162.256	3.72336	3.77845	3.80298
97	3.797676667	9.89196	1.435	162.256	3.75708	3.80929	3.82666
98	3.82375	9.89196	1.435	162.256	3.78117	3.835	3.85508
99	3.83697	9.72655	1.411	159.543	3.7908	3.85556	3.86455
100	3.84505	9.72655	1.411	159.543	3.80043	3.8607	3.87402
950	6.311586667	10.7191	1.555	175.823	6.44966	6.14837	6.33673
951	6.309853333	10.5536	1.531	173.109	6.44966	6.14317	6.33673
952	6.30164	10.5536	1.531	173.109	6.44002	6.13287	6.33203
953	6.29343	10.5536	1.531	173.109	6.43039	6.12267	6.32723
954	6.278873333	10.7191	1.555	175.823	6.41594	6.11235	6.30833
955	6.27224	10.7191	1.555	175.823	6.41112	6.10207	6.30353
956	6.27082	10.5536	1.531	173.109	6.41112	6.10721	6.29413
957	6.26086	10.5536	1.531	173.109	6.39667	6.09178	6.29413
958	6.24457	10.5536	1.531	173.109	6.38222	6.07636	6.27513
959	6.239833333	10.5536	1.531	173.109	6.37741	6.07636	6.26573
960	6.23808	10.5536	1.531	173.109	6.37259	6.07122	6.27043
961	6.224996667	10.5536	1.531	173.109	6.36296	6.0558	6.25623
962	6.220183333	10.5536	1.531	173.109	6.35332	6.0558	6.25143
963	6.215043333	10.5536	1.531	173.109	6.35332	6.04038	6.25143
964	6.210306667	10.5536	1.531	173.109	6.34851	6.04038	6.24203
965	6.192186667	10.5536	1.531	173.109	6.33406	6.01467	6.22783
966	6.1842	10.5536	1.531	173.109	6.3196	6.01467	6.21833
967	6.177603333	10.3882	1.507	170.396	6.31479	6.00439	6.21363
968	6.171116667	10.3882	1.507	170.396	6.30997	5.99925	6.20413
969	6.159706667	10.3882	1.507	170.396	6.29552	5.98897	6.19463
970	6.151503333	10.7191	1.555	175.823	6.28589	5.97869	6.18993
971	6.14491	10.3882	1.507	170.396	6.28589	5.96841	6.18043
972	6.1335	10.5536	1.531	173.109	6.27144	5.95813	6.17093
973	6.130366667	10.3882	1.507	170.396	6.27144	5.95813	6.16153
974	6.12227	10.3882	1.507	170.396	6.2618	5.95298	6.15203
975	6.12865	10.3882	1.507	170.396	6.27144	5.95298	6.16153
976	6.135213333	10.5536	1.531	173.109	6.27144	5.96327	6.17093
977	6.13853	10.5536	1.531	173.109	6.27625	5.96841	6.17093
978	6.145123333	10.5536	1.531	173.109	6.27625	5.97869	6.18043
979	6.143303333	10.5536	1.531	173.109	6.28107	5.96841	6.18043
980	6.14819	10.7191	1.555	175.823	6.28589	5.97355	6.18513
981	6.153	10.5536	1.531	173.109	6.29552	5.97355	6.18993
982	6.166083333	10.3882	1.507	170.396	6.30515	5.98897	6.20413
983	6.16951	10.2228	1.483	167.683	6.30515	5.99925	6.20413
984	6.17932	10.5536	1.531	173.109	6.3196	6.00953	6.20883
985	6.182526667	10.3882	1.507	170.396	6.32442	6.00953	6.21363
986	6.190586667	10.3882	1.507	170.396	6.33406	6.01467	6.22303
987	6.196923333	10.5536	1.531	173.109	6.33887	6.01467	6.23723
988	6.2005	10.7191	1.555	175.823	6.33887	6.0301	6.23253
989	6.213586667	10.5536	1.531	173.109	6.34851	6.04552	6.24673
990	6.215083333	10.5536	1.531	173.109	6.35814	6.04038	6.24673
991	6.223283333	10.5536	1.531	173.109	6.36296	6.05066	6.25623
992	6.226346667	10.5536	1.531	173.109	6.37259	6.04552	6.26093
993	6.231373333	10.5536	1.531	173.109	6.37259	6.0558	6.26573
994	6.237826667	10.3882	1.507	170.396	6.37741	6.06094	6.27513
995	6.25095	10.3882	1.507	170.396	6.39186	6.07636	6.28463
996	6.259153333	10.7191	1.555	175.823	6.40149	6.08664	6.28933
997	6.26575	10.5536	1.531	173.109	6.40149	6.09693	6.29883
998	6.27534	10.5536	1.531	173.109	6.42076	6.09693	6.30833
999	6.280263333	10.5536	1.531	173.109	6.43039	6.10207	6.30833
1000	6.285216667	10.7191	1.555	175.823	6.42557	6.11235	6.31773
1001	6.288466667	10.5536	1.531	173.109	6.44002	6.11235	6.31303
1002	6.303246667	10.5536	1.531	173.109	6.44484	6.13287	6.33203
1003	6.30642	10.7191	1.555	175.823	6.44966	6.13287	6.33673
1004	6.316096667	10.7191	1.555	175.823	6.45929	6.13807	6.35093
1005	6.31953	10.7191	1.555	175.823	6.45929	6.14837	6.35093
1006	6.33248	10.7191	1.555	175.823	6.47374	6.15857	6.36513
1007	6.343896667	10.5536	1.531	173.109	6.48819	6.16887	6.37463
1008	6.35537	10.5536	1.531	173.109	6.49301	6.18427	6.38883
1009	6.36192	10.7191	1.555	175.823	6.50746	6.18947	6.38883
1010	6.36852	10.5536	1.531	173.109	6.50746	6.19977	6.39833

Tire Bale 4 - Unconfined
Under a Cyclic Load of 9 kips
Peak - Minimum Values
Representative Data

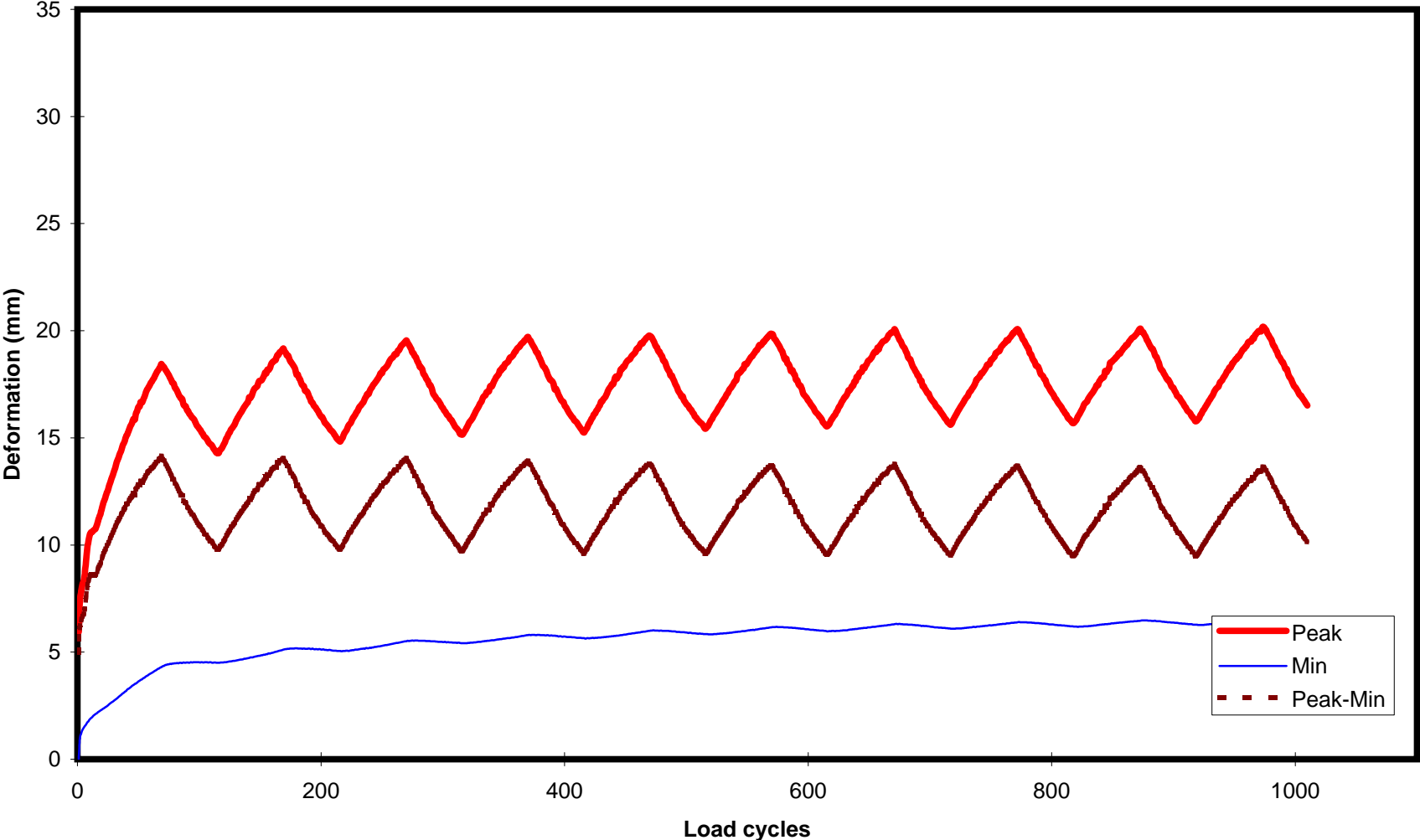
Cycle #	Gen. Def.	LC (kPa)	LC (psi)	LC (lbf)	SD3 (mm)	SD4 (mm)	SD5 (mm)
1	22.86969	517.4256	75.044	8487.231	22.75925	23.34923	22.50059
2	23.00455667	516.7646	74.948	8476.389	22.91816	23.46237	22.63314
3	22.92195667	512.29804	74.300	8403.124	22.83149	23.40067	22.53371
4	22.84348	510.1476	73.988	8367.851	22.73994	23.31839	22.47211
5	22.74707333	507.3352	73.580	8321.720	22.63879	23.21557	22.38686
6	22.77967667	508.32804	73.724	8338.005	22.66775	23.2465	22.42478
7	22.51877333	500.8836	72.644	8215.896	22.41725	22.98425	22.15482
8	22.47276667	498.40304	72.285	8175.208	22.37875	22.92256	22.11699
9	22.38627667	495.25945	71.829	8123.644	22.28717	22.8352	22.03646
10	22.28383333	492.77887	71.469	8082.955	22.18608	22.74265	21.92277
11	22.13991	489.30445	70.965	8025.965	22.04155	22.5833	21.79488
12	22.14349667	487.15404	70.653	7990.692	22.04633	22.59874	21.78542
13	22.11347333	484.83887	70.317	7952.717	22.0271	22.54215	21.77117
14	22.03861	481.52987	69.838	7898.440	21.95488	22.47021	21.69074
15	21.94673	478.22187	69.358	7844.180	21.89705	22.35192	21.59122
16	21.95146667	475.40945	68.950	7798.048	21.89226	22.35196	21.61018
17	21.88609	473.42445	68.662	7765.489	21.83439	22.28002	21.54386
18	21.81038667	470.94387	68.302	7724.800	21.76699	22.17715	21.48702
19	21.71912	468.29687	67.918	7681.382	21.66581	22.08975	21.4018
20	21.75205333	466.97387	67.726	7659.681	21.70441	22.13095	21.4208
21	21.50433	464.32687	67.343	7616.263	21.45394	21.88933	21.16972
22	21.49114	462.17645	67.031	7580.990	21.45388	21.86876	21.15078
23	21.48281333	461.51445	66.935	7570.131	21.42023	21.85848	21.16973
24	21.26427667	458.37187	66.479	7518.584	21.21308	21.63736	20.94239
25	21.16128667	456.55229	66.215	7488.738	21.11189	21.52428	20.84769
26	21.15354	455.72487	66.095	7475.166	21.11189	21.52946	20.81927
27	20.93290333	451.75487	65.519	7410.047	20.89521	21.28783	20.61567
28	20.89223	451.09387	65.423	7399.204	20.85179	21.25187	20.57303
29	20.81411333	449.27429	65.159	7369.358	20.77469	21.17989	20.48776
30	20.65588	447.12387	64.848	7334.085	20.61096	21.02047	20.33621
31	20.57741667	445.79987	64.656	7312.368	20.53871	20.93313	20.26041
32	20.49615	443.98029	64.392	7282.522	20.45679	20.86115	20.17051
33	20.41288333	442.32645	64.152	7255.394	20.37497	20.77371	20.08997
34	20.30830667	441.33429	64.008	7239.120	20.27376	20.66063	19.99053
35	20.20429667	439.34929	63.720	7206.560	20.15334	20.57329	19.88626
36	20.15522333	438.1907	63.552	7187.556	20.10521	20.51673	19.84373
37	20.05064333	436.2057	63.264	7154.997	20.00409	20.40365	19.74419
38	20.00814667	434.55187	63.024	7127.869	19.96549	20.3574	19.70155
39	19.92846667	434.2207	62.976	7122.437	19.87886	20.28542	19.62112
40	20.05396333	435.37929	63.144	7141.441	20.01366	20.40872	19.73951
41	20.21903	440.1757	63.840	7220.116	20.17261	20.58868	19.8958
42	20.27739	441.99529	64.104	7249.962	20.23044	20.63496	19.96677
43	20.39817667	444.64229	64.488	7293.380	20.35571	20.7583	20.08052
44	20.51892667	446.29645	64.728	7320.513	20.48087	20.88173	20.19418
45	20.66107333	449.93529	65.255	7380.201	20.6158	21.03595	20.33147
46	20.71309333	451.75487	65.519	7410.047	20.66872	21.08223	20.38833
47	20.79458667	453.07887	65.711	7431.764	20.741	21.16447	20.47829
48	21.04749	456.22145	66.167	7483.311	21.00117	21.42149	20.71981
49	21.10294667	459.03387	66.575	7529.443	21.05409	21.47808	20.77667
50	21.24498667	460.52229	66.791	7553.857	21.19384	21.62716	20.91396
51	21.30876333	462.01104	67.007	7578.277	21.25639	21.69908	20.97082
52	21.47666333	465.64987	67.534	7637.964	21.425	21.86362	21.14137
53	21.53676333	466.97387	67.726	7659.681	21.4924	21.91497	21.20292
54	21.62830667	468.79345	67.990	7689.527	21.56953	22.01781	21.29758
55	21.71171333	470.94387	68.302	7724.800	21.65138	22.11033	21.37343
56	21.77181667	472.26687	68.494	7746.501	21.70922	22.16178	21.44445
57	21.91546667	474.74845	68.854	7787.206	21.85853	22.31086	21.57701
58	21.98043333	475.57487	68.974	7800.762	21.92108	22.36736	21.65286
59	22.13399333	478.05645	69.334	7841.466	22.0705	22.53189	21.79959
60	22.17483667	479.37945	69.526	7863.167	22.12341	22.57303	21.82807
61	22.19772667	480.04145	69.622	7874.026	22.14275	22.59871	21.85172
62	22.42784333	485.33445	70.389	7960.846	22.35468	22.8403	22.08855
63	22.52211	487.31945	70.677	7993.406	22.45576	22.92258	22.18799
64	22.60380667	487.98145	70.773	8004.264	22.53771	23.00996	22.26375
65	22.69209333	491.12404	71.229	8055.812	22.6196	23.10765	22.34903
66	22.70506667	490.62845	71.157	8047.682	22.63398	23.11797	22.36325
67	22.86857333	494.59845	71.733	8112.802	22.79778	23.29787	22.51007
68	22.92539	495.09404	71.805	8120.931	22.86999	23.34408	22.5621
69	22.98083667	495.75604	71.901	8131.789	22.91819	23.40068	22.62364
70	23.06391	497.90645	72.213	8167.062	22.99041	23.48292	22.7184
71	23.16692333	500.38804	72.573	8207.767	23.09159	23.59607	22.81311
72	23.25641333	501.71104	72.764	8229.468	23.20241	23.67317	22.89366
73	23.34150333	503.86145	73.076	8264.741	23.26499	23.77594	22.98358
74	23.34804667	502.53845	72.884	8243.040	23.27469	23.78112	22.98833
75	23.57819	505.68104	73.340	8294.587	23.49144	24.02271	23.22042
76	23.57949333	505.01904	73.244	8283.728	23.49141	24.01247	23.2346
77	23.71678667	508.32804	73.724	8338.005	23.63109	24.16149	23.35778
78	23.84080667	510.97504	74.108	8381.424	23.75629	24.29	23.47613
79	23.86017333	509.81645	73.940	8362.419	23.77555	24.30036	23.50461

80	23.92392667	510.8096	74.084	8378.710	23.82857	24.37231	23.5709
81	24.00863333	512.29804	74.300	8403.124	23.91527	24.45455	23.65608
82	24.12148667	514.28304	74.588	8435.684	24.03565	24.57792	23.75089
83	24.20306	515.60604	74.780	8457.385	24.09833	24.6653	23.84555
84	24.23389333	514.7796	74.660	8443.829	24.15125	24.68587	23.86456
85	24.30100333	516.93004	74.972	8479.102	24.21393	24.76297	23.92611
86	24.35786333	517.59104	75.068	8489.945	24.26203	24.81443	23.99713
87	24.45877667	518.91504	75.260	8511.662	24.34883	24.91202	24.11548
88	24.43954	518.25304	75.164	8500.803	24.34398	24.90178	24.07286
89	24.5962	521.72645	75.667	8557.777	24.50775	25.06117	24.21968
90	24.64685	522.0576	75.715	8563.209	24.54625	25.11771	24.27659
91	24.64037333	521.72645	75.667	8557.777	24.54628	25.1125	24.26234
92	24.82344667	524.87004	76.123	8609.341	24.72928	25.313	24.42806
93	24.78229	523.8772	75.979	8593.055	24.68593	25.25651	24.40443
94	24.93914667	526.0276	76.291	8628.328	24.84006	25.42613	24.55125
944	22.69595	479.7109	69.574	7868.604	22.84115	23.3287	21.918
945	22.62002	477.5605	69.262	7833.331	22.71106	23.231	21.918
946	22.56824333	475.9064	69.022	7806.200	22.63403	23.1385	21.9322
947	22.47182333	471.7709	68.422	7738.366	22.48947	22.9843	21.9417
948	22.39353333	468.9585	68.014	7692.234	22.3835	22.8507	21.9464
949	22.35843333	467.8009	67.846	7673.247	22.3257	22.789	21.9606
950	22.28901	465.1539	67.462	7629.828	22.20053	22.6964	21.9701
951	22.18514333	462.6724	67.103	7589.125	22.06563	22.5576	21.9322
952	22.13459	461.3494	66.911	7567.424	22.01747	22.5062	21.8801
953	21.96593333	457.3794	66.335	7502.305	21.8537	22.3108	21.7333
954	21.92859	455.8909	66.119	7477.889	21.81035	22.28002	21.6954
955	21.83099	454.5669	65.927	7456.172	21.71887	22.1875	21.5866
956	21.70841	452.0864	65.567	7415.485	21.58397	22.05896	21.4823
957	21.65273667	450.1014	65.279	7382.925	21.54062	21.99209	21.4255
958	21.55149333	448.1164	64.992	7350.366	21.43947	21.88421	21.3308
959	21.45869667	445.4694	64.608	7306.947	21.32868	21.80191	21.2455
960	21.34928333	444.1464	64.416	7285.246	21.2371	21.68365	21.1271
961	21.29036667	442.1614	64.128	7252.687	21.16973	21.61687	21.0845
962	21.20404667	440.8374	63.936	7230.970	21.08297	21.53457	20.9946
963	21.08532	437.5294	63.456	7176.709	20.96737	21.42659	20.862
964	20.99209	436.2064	63.264	7155.008	20.87588	21.32379	20.7766
965	20.86667667	433.5594	62.880	7111.590	20.73623	21.2056	20.6582
966	20.79639667	431.5744	62.592	7079.030	20.69289	21.1233	20.573
967	20.71132667	429.7548	62.328	7049.184	20.6013	21.03078	20.5019
968	20.63951333	428.4308	62.136	7027.467	20.52912	20.95372	20.4357
969	20.42265667	422.4758	61.273	6929.788	20.31237	20.7378	20.2178
970	20.45042667	424.1299	61.513	6956.920	20.3412	20.76858	20.2415
971	20.24838667	419.1678	60.793	6875.527	20.1293	20.57326	20.0426
972	20.34459667	422.3104	61.249	6927.075	20.24005	20.66584	20.1279
973	20.39323	423.7998	61.465	6951.505	20.27865	20.70694	20.1941
974	20.46649333	425.1228	61.657	6973.206	20.36529	20.77379	20.2604
975	20.64961333	430.4158	62.424	7060.026	20.52905	20.97939	20.4404
976	20.74741667	432.2354	62.688	7089.873	20.64465	21.0719	20.5257
977	20.7896	433.5594	62.880	7111.590	20.67844	21.10786	20.5825
978	20.84180667	434.2214	62.976	7122.449	20.73624	21.15928	20.6299
979	20.98076	438.1914	63.552	7187.568	20.86622	21.31356	20.7625
980	21.08654	440.0109	63.816	7217.413	20.977	21.41122	20.8714
981	21.17969667	442.1614	64.128	7252.687	21.06377	21.51402	20.9613
982	21.27101333	444.9728	64.536	7298.802	21.16974	21.6014	21.0419
983	21.39188667	447.7852	64.943	7344.933	21.26604	21.73512	21.1745
984	21.45994333	448.7774	65.087	7361.208	21.34789	21.78644	21.2455
985	21.57433667	452.2518	65.591	7418.198	21.45877	21.90984	21.3544
986	21.63824333	454.2368	65.879	7450.757	21.50693	21.987	21.4208
987	21.73627333	455.3944	66.047	7469.745	21.61772	22.0898	21.5013
988	21.81746333	457.8759	66.407	7510.449	21.71402	22.15657	21.5818
989	21.90917667	459.3644	66.623	7534.864	21.80068	22.26455	21.6623
990	22.01198	462.6724	67.103	7589.125	21.88745	22.37249	21.776
991	21.99101333	462.0114	67.007	7578.283	21.86333	22.36221	21.7475
992	22.12465	465.3194	67.486	7632.543	22.0078	22.49075	21.8754
993	22.18529	465.9814	67.583	7643.402	22.0656	22.56277	21.9275
994	22.32933667	470.1168	68.182	7711.234	22.23418	22.72213	22.0317
995	22.30934667	469.4548	68.086	7700.375	22.21973	22.68611	22.0222
996	22.33457667	470.4469	68.230	7716.648	22.2487	22.73753	22.0175
997	22.40078	473.2594	68.638	7762.781	22.3643	22.83004	22.008
998	22.45755667	475.9064	69.022	7806.200	22.44133	22.93284	21.9985
999	22.49246667	476.5674	69.118	7817.042	22.4895	22.9894	21.9985
1000	22.50081333	476.4019	69.094	7814.327	22.51362	22.99972	21.9891
1001	22.59046333	479.8764	69.598	7871.319	22.63397	23.14362	21.9938
1002	22.62195	481.8614	69.886	7903.878	22.70625	23.1848	21.9748
1003	22.65861	482.3569	69.957	7912.006	22.75923	23.2465	21.9701
1004	22.6951	483.6809	70.150	7933.723	22.8074	23.303	21.9749
1005	22.77826667	486.9889	70.629	7987.984	22.9423	23.4366	21.9559
1006	22.81201667	488.3119	70.821	8009.685	22.98565	23.5087	21.9417
1007	22.84686667	489.8014	71.037	8034.117	23.0483	23.5601	21.9322
1008	22.88162667	491.1244	71.229	8055.817	23.12048	23.6064	21.918
1009	22.94147667	492.9439	71.493	8085.662	23.20243	23.704	21.918
1010	22.89504333	491.7864	71.325	8066.676	23.14463	23.632	21.9085

**Tire Bale 4 - Unconfined
Average Center Deformation
Under a Cyclic Load of 9 kips**



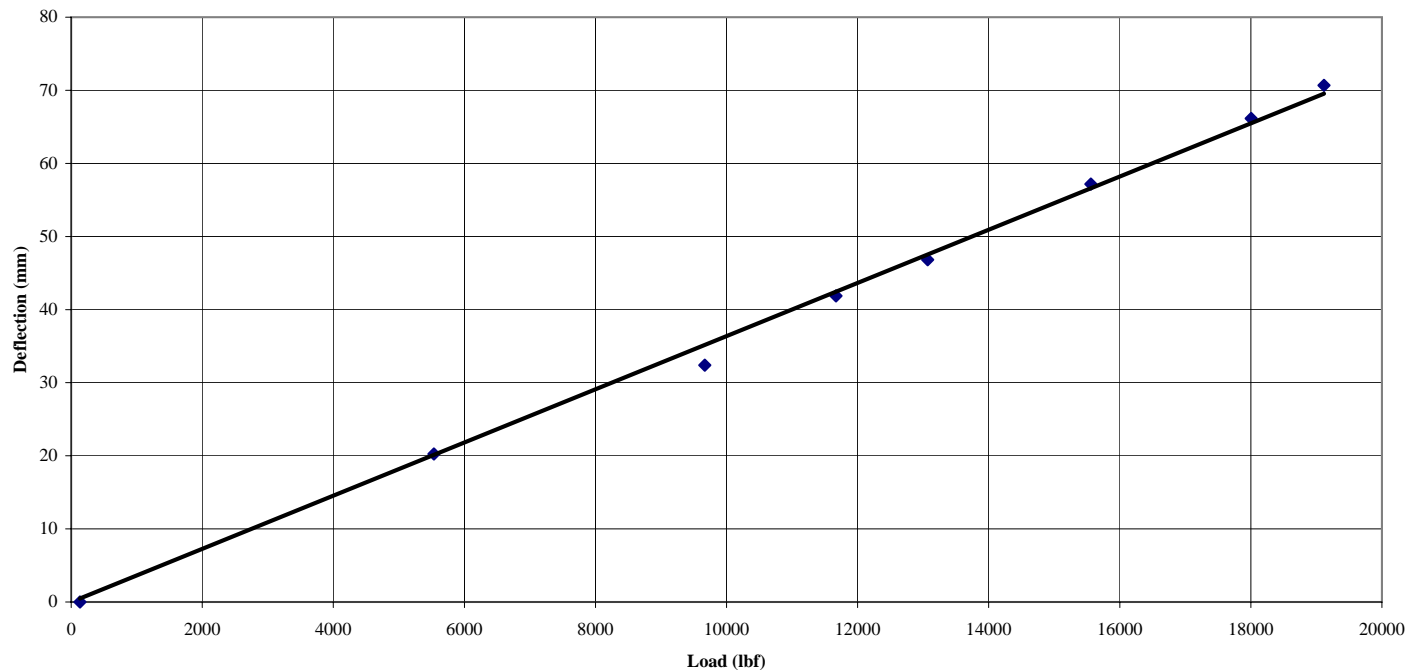
**Tire Bale 3 - Confined
Average Center Deformation
Under a Cyclic Load of 9 kips**



Tire Bale 4 - Unconfined Compressibility at Static Working Loads

Load (voltage)				SD3		SD4			SD5			Average Deflection	
	(kPa)	(psi)	(lbf)	(voltage)	(mm)	(change mm)	(voltage)	(mm)	(change mm)	(voltage)	(mm)	(change mm)	(mm)
-3.94	8.1306	1.179202	133.3646	-7	-13.33714	0	-5.03	-3.032136	0	-5.02	-2.870978	0	0
-1.51	337.4199	48.9369	5534.633	-1.93	6.668571	20.005713	0.5	20.25635	23.288489	-0.52	14.58767	17.45865	20.25095067
0.35	589.4685	85.49217	9668.936	0	14.28416	27.6213	4	34.9959	38.028039	3.1	28.63219	31.503164	32.38416767
1.25	711.4275	103.1802	11669.41	1.23	19.13762	32.474757	7.51	49.77757	52.809702	5.37	37.43911	40.310083	41.86484733
1.88	796.7988	115.5618	13069.73	1.77	21.2684	34.605543	9.2	56.89466	59.926799	6.81	43.02587	45.896851	46.809731
3	948.57	137.5736	15559.21	3.64	28.64723	41.984376	12.15	69.318	72.350134	9.72	54.3158	57.186778	57.17376267
4.1	1097.631	159.1923	18004.23	5.75	36.97308	50.310225	14.25	78.16173	81.193864	12.24	64.09264	66.963622	66.15590367
4.6	1165.386	169.019	19115.6	7.14	42.45788	55.795026	15.42	83.08895	86.121085	13.05	67.2352	70.106179	70.67409667

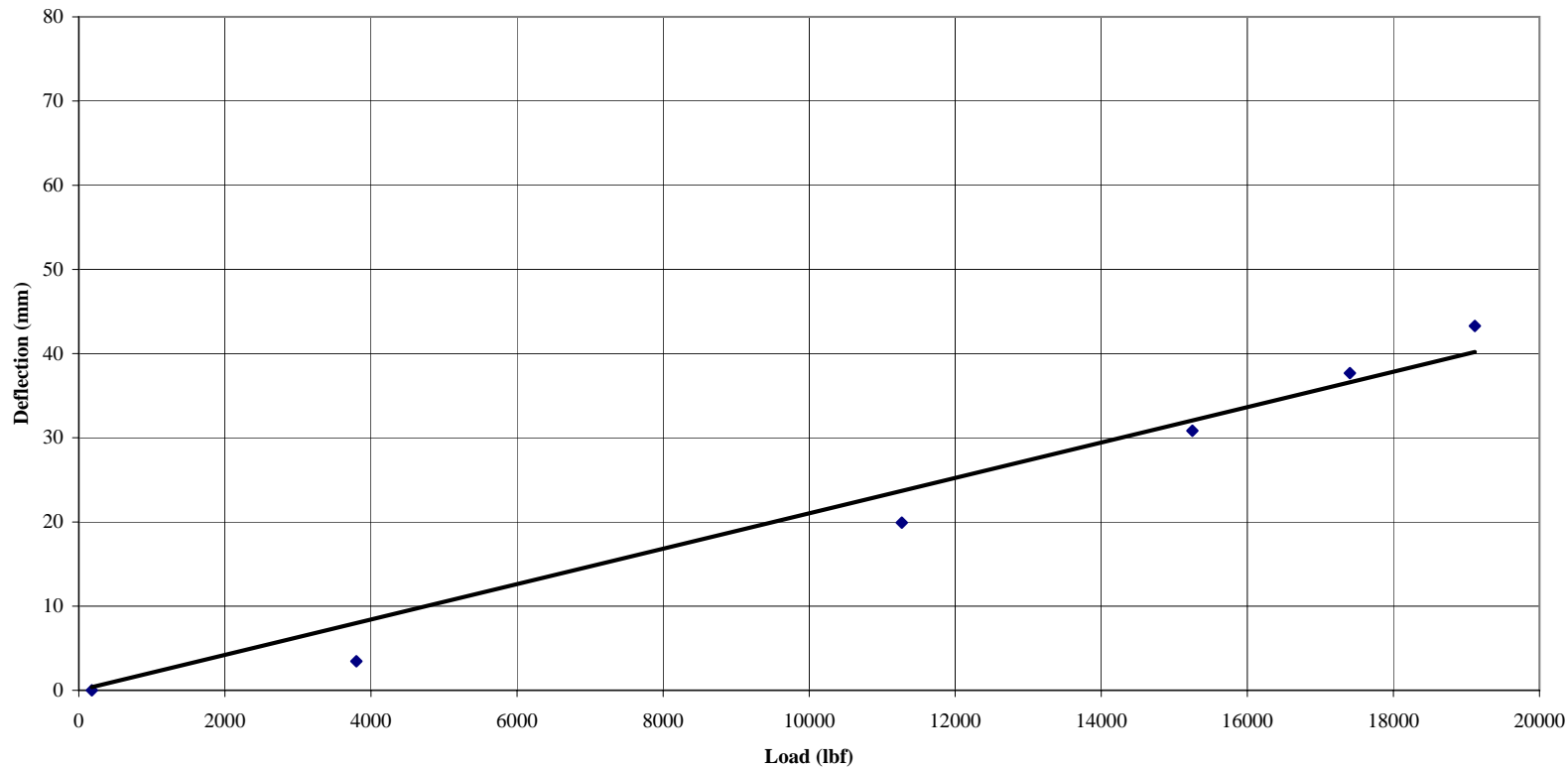
Tire Bale 4 - Unconfined Compressibility at Static Working Loads



Tire Bale 3 - Confined Compressibility at Static Working Loads

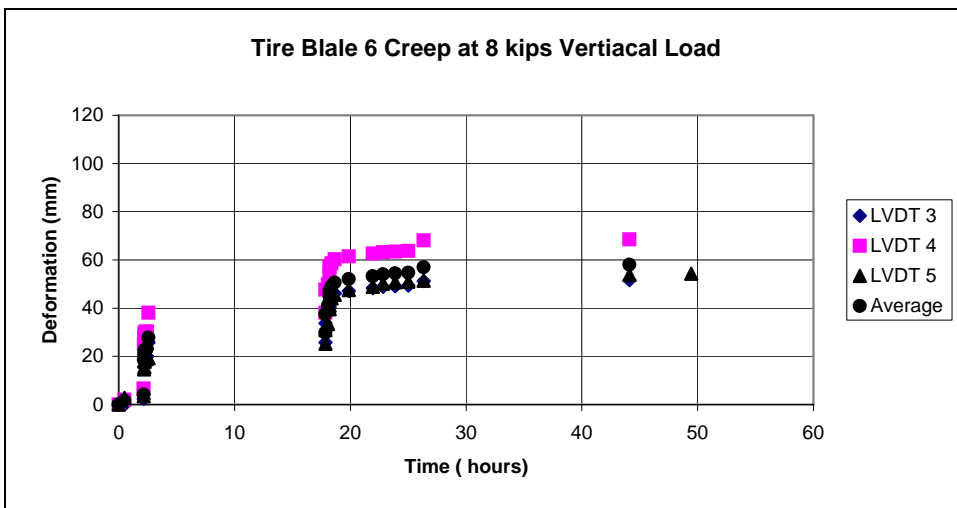
Load	SD3			SD4			SD5			Average Deflection			
(voltage)	(kPa)	(psi)	(lbf)	(voltage)	(mm)	(change mm)	(voltage)	(mm)	(change mm)	(voltage)	(mm)	(change mm)	(mm)
-3.92	10.8408	1.57227	177.8195	-6.08	-9.706914	0	-5.31	-4.2113	0	-5.18	-3.49173	0	0
-2.29	231.7221	33.60727	3800.892	-6.04	-9.549078	0.157836	-3.52	3.326927	7.538227	-4.5	-0.853534	2.638196	3.444753
1.07	687.0357	99.6426	11269.31	-4.47	-3.354015	6.352899	3.17	31.50052	35.711824	-0.62	14.1997	17.691432	19.91871833
2.86	929.5986	134.8221	15248.02	-2.54	4.261572	13.968486	6.71	46.40853	50.619826	2.02	24.44211	27.93384	30.84071733
3.83	1061.043	153.8859	17404.09	-1.55	8.168013	17.874927	9.25	57.10523	61.316528	3.55	30.37805	33.869781	37.68707867
4.6	1165.386	169.019	19115.6	-0.69	11.56149	21.268401	11.45	66.37009	70.581388	4.61	34.49053	37.982263	43.27735067

Tire Bale 3 - Confined Compressibility at Static Working Loads

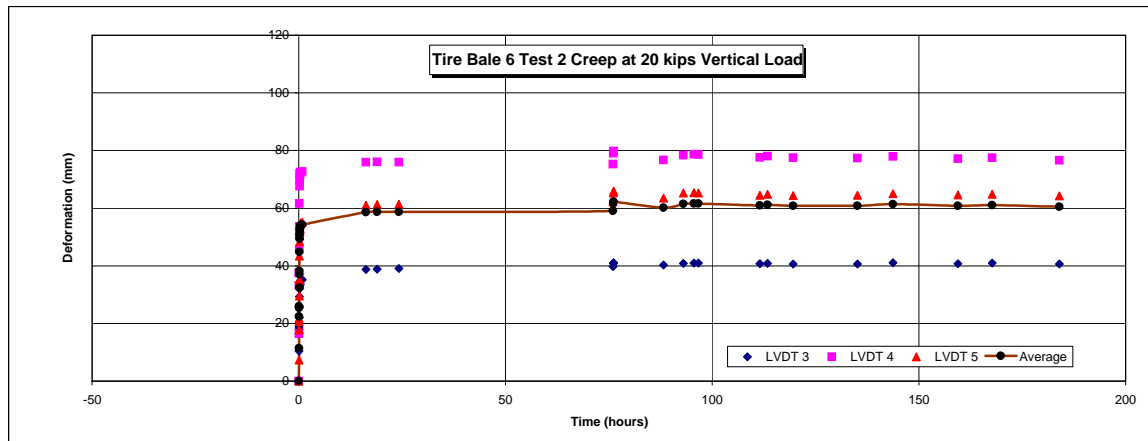


Bale 6 8 kips

Date	Time	Time Interval (hr)	Deformation				
			LVDT 3 (mm)	LVDT 4 (mm)	LVDT 5 (mm)	Average (mm)	
5/8/2004	21:45	5/8/2004 21:45	0.00	0	0	0	0
5/8/2004	21:57	5/8/2004 21:57	0.20	29.12074	12.84447	8.108573	16.69126
5/8/2004	21:59	5/8/2004 21:59	0.23	35.5131	17.94014	10.70797	21.38707
5/8/2004	22:04	5/8/2004 22:04	0.32	36.06553	22.362	13.11339	23.84697167
5/9/2004	10:06	5/9/2004 10:06	12.35	38.86712	23.28849	13.61775	25.25778367
5/9/2004	10:35	5/9/2004 10:35	12.83	39.34062	23.87807	14.08331	25.767335
5/9/2004	10:40	5/9/2004 10:40	12.92	39.459	24.00441	14.1997	25.887704
5/9/2004	14:55	5/9/2004 14:55	17.17	42.18167	27.41556	16.8767	28.824643
5/9/2004	15:16	5/9/2004 15:16	17.52	42.22113	27.45768	16.95429	28.87769833
6/2/2004	15:35	6/2/2004 15:35	0.00	0	0	0	0
6/2/2004	16:05	6/2/2004 16:05	0.50	-0.039459	1.979311	2.793384	1.577745333
6/2/2004	17:45	6/2/2004 17:45	2.17	2.36754	6.611741	3.49173	4.157003667
6/2/2004	17:46	6/2/2004 17:46	2.18	15.62576	24.88878	14.66527	18.393271
6/2/2004	17:47	6/2/2004 17:47	2.20	18.42735	28.25782	15.5188	20.73465867
6/2/2004	17:50	6/2/2004 17:50	2.25	19.53221	29.77389	17.76903	22.358374
6/2/2004	17:54	6/2/2004 17:54	2.32	19.84788	30.1108	18.73895	22.89920767
6/2/2004	18:00	6/2/2004 18:00	2.42	19.88734	30.06868	19.04933	23.00178167
6/2/2004	18:01	6/2/2004 18:01	2.43	20.04517	30.27925	19.08812	23.13751433
6/2/2004	18:10	6/2/2004 18:10	2.58	25.72727	38.07015	19.24331	27.680244
6/3/2004	9:26	6/3/2004 9:26	17.85	25.72727	38.07015	25.25685	29.68475567
6/3/2004	9:27	6/3/2004 9:27	17.87	33.69799	47.6298	30.92121	37.41633267
6/3/2004	9:40	6/3/2004 9:40	18.08	39.26171	49.94602	33.40422	40.87064667
6/3/2004	9:47	6/3/2004 9:47	18.20	40.44548	54.66267	39.57294	44.89369633
6/3/2004	9:48	6/3/2004 9:48	18.22	43.20761	57.35791	40.96963	47.178381
6/3/2004	9:58	6/3/2004 9:58	18.38	44.43083	58.57918	44.0346	49.01487067
6/3/2004	10:15	6/3/2004 10:15	18.67	46.04865	60.2637	45.47008	50.59414667
6/3/2004	11:28	6/3/2004 11:28	19.88	47.11405	61.48498	47.52633	52.04178367
6/3/2004	13:32	6/3/2004 13:32	21.95	48.33728	62.62203	48.88422	53.28117533
6/3/2004	14:25	6/3/2004 14:25	22.83	48.85024	63.12739	50.16452	54.04738333
6/3/2004	15:27	6/3/2004 15:27	23.87	49.16591	63.42218	50.70768	54.43192367
6/3/2004	16:35	6/3/2004 16:35	25.00	49.40267	63.67486	51.01806	54.69852633
6/3/2004	17:55	6/3/2004 17:55	26.33	51.2967	68.05461	51.32843	56.89324633
6/4/2004	11:42	6/4/2004 11:42	44.12	51.65183	68.51785	53.81144	57.993707
6/4/2004	17:02	6/4/2004 17:02	49.45			54.3546	



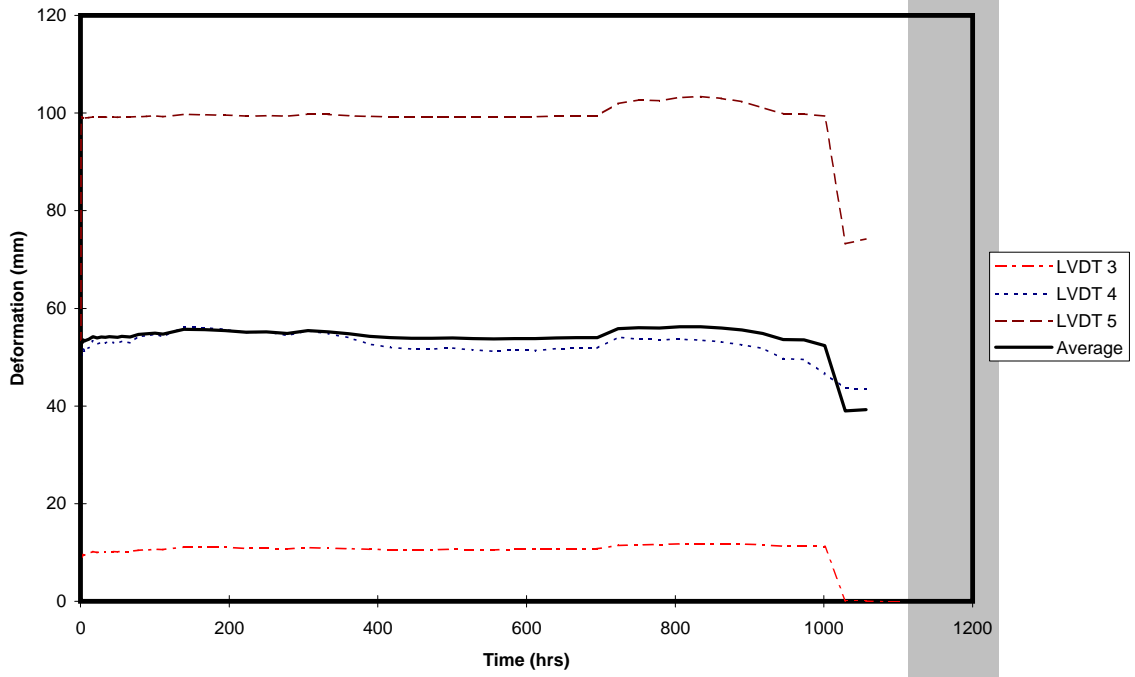
Tire Bale 6 Test 2 Creep at 20 kips Vertical Load																					
Date Time	Change in Time (days)	Change in Time (hrs)	Load Cell				Voltage	Corr. Displ. (mm)	Voltage	Corr. Displ. (mm)	Voltage	Corr. Displ. (mm)	LVDT 3 (mm)	LVDT 4 (mm)	LVDT 5 (mm)	Average (mm)					
			voltage	(kPa)	(psi)	(lbf)															
9/9/2004 16:53	0	0.00	-4.00	0.00	0.00	0.00	-4.77	-33.106101	-5.36	-40.723271	-5.23	-36.895947	0	0	0	0					
9/9/2004 16:56	0.002083333	0.05	-3.00	135.51	19.65	2222.74	-2.12	-22.649466	-1.45	-24.257088	-3.33	-29.524517	10.45664	16.46618	7.37143	11.43142					
9/9/2004 16:57	0.002777778	0.07	-0.10	528.49	76.65	8668.70	-0.59	-16.612239	2.51	-7.58034	-0.65	-19.126921	16.49386	33.14293	17.76903	22.46861					
9/9/2004 16:58	0.003472222	0.08	0.30	582.69	84.51	9557.80	-0.2	-15.073338	3.55	-3.200588	0.1	-16.217146	18.03276	37.52268	20.6788	25.41142					
9/9/2004 16:58	0.003472222	0.08	0.57	619.28	89.82	10157.94	-0.01	-14.323617	-5.1	-3.200588	0.37	-15.169627	18.78248	37.52268	21.72632	26.0105					
9/9/2004 17:00	0.004861111	0.12	1.50	745.31	108.09	12225.09	0.84	-10.969602	-3.15	5.011447	2.37	-7.410227	22.1365	45.73472	29.48572	32.45231					
9/9/2004 17:01	0.005555556	0.13	2.50	880.82	127.75	14447.84	1.7	-7.576128	-2	9.854442	3.8	-1.862256	25.52997	50.57771	35.03369	37.04713					
9/9/2004 17:01	0.005555556	0.13	2.57	890.30	129.12	14603.43	1.8	-7.181538	-1.28	12.886578	-5.05	-1.862256	25.92456	53.60985	35.03369	38.18937					
9/9/2004 17:04	0.007638889	0.18	3.50	1016.33	147.40	16670.58	2.67	-3.748605	0.62	20.888048	-2.89	6.517896	29.3575	61.61132	43.41384	44.79422					
9/9/2004 17:05	0.008333333	0.20	4.20	1111.18	161.16	18226.50	3.39	-0.907557	2.05	26.910207	-1.6	11.522709	32.19854	67.63348	48.41866	49.41689					
9/9/2004 17:05	0.008333333	0.20	4.35	1131.51	164.11	18559.91	-5.35	-0.907557	2.54	28.973744	-1.09	13.501356	32.19854	69.69702	50.3973	50.76429					
9/9/2004 17:11	0.0125	0.30	4.42	1140.99	165.48	18715.50	-5.11	0.039459	2.88	30.405586	-0.7	15.014439	33.14556	71.12886	51.91039	52.0616					
9/9/2004 17:13	0.013888889	0.33	4.49	1150.48	166.86	18871.10	-4.98	0.552426	3.09	31.289959	-0.49	15.829176	33.65853	72.01323	52.72512	52.79896					
9/9/2004 17:13	0.013888889	0.33	4.52	1154.55	167.45	18937.78	-4.95	0.670803	-5.26	31.289959	-0.46	15.945567	33.7769	72.01323	52.84151	52.87722					
9/9/2004 17:18	0.017361111	0.42	4.66	1173.52	170.20	19248.96	-4.73	1.538901	-5.17	31.668976	-0.03	17.613838	34.645	72.39225	54.50979	53.84901					
9/9/2004 17:22	0.020138889	0.48	4.59	1164.03	168.82	19093.37	-4.66	1.815114	-5.16	31.711089	0.06	17.963011	34.92122	72.43436	54.85896	54.07151					
9/9/2004 17:45	0.036111111	0.87	4.60	1165.39	169.02	19115.60	-4.6	2.051868	-5.1	31.963767	0.13	18.23459	35.15797	72.68704	55.13054	54.32518					
9/10/2004 9:08	0.677083333	16.25	4.39	1136.93	164.89	18648.82	-3.68	5.682096	-4.33	35.206468	1.67	24.209328	38.7882	75.92974	61.10528	58.60774					
9/10/2004 11:49	0.788888889	18.93	4.37	1134.22	164.50	18604.37	-3.65	5.800473	-4.31	35.290694	1.7	24.325719	38.90657	76.01397	61.22167	58.71407					
9/10/2004 17:05	1.008333333	24.20	4.32	1127.44	163.52	18493.23	-3.62	5.91885	-4.32	35.248581	1.73	24.44211	39.02495	75.97185	61.33806	58.77829					
9/12/2004 20:52	3.165972222	75.98	3.78	1054.27	152.90	17292.95	-3.43	6.668571	-4.48	34.574773	1.93	25.21805	39.77467	75.29804	62.114	59.06224					
9/12/2004 20:58	3.170138889	76.08	4.54	1157.26	167.84	18982.23	-3.15	7.773423	-3.59	38.32283	2.75	28.399404	40.87952	79.0461	65.29535	61.74033					
9/12/2004 21:04	3.174305556	76.18	4.64	1170.81	169.81	19204.51	-3.1	7.970718	-3.42	39.038751	2.92	29.058953	41.07682	79.76202	65.9549	62.26458					
9/13/2004 9:07	3.676388889	88.23	3.99	1082.72	157.03	17759.72	-3.29	7.220997	-4.15	35.964502	2.28	26.575945	40.3271	76.68777	63.47189	60.16225					
9/13/2004 13:54	3.875694444	93.02	4.34	1130.15	163.91	18537.69	-3.15	7.773423	-3.74	37.691135	2.73	28.32181	40.87952	78.41441	65.21776	61.5039					
9/13/2004 16:27	3.981944444	95.57	4.34	1130.15	163.91	18537.69	-3.14	7.812882	-3.68	37.943813	2.76	28.438201	40.91898	78.66708	65.33415	61.64007					
9/13/2004 17:35	4.029166667	96.70	4.34	1130.15	163.91	18537.69	-3.13	7.852341	-3.7	37.859587	2.75	28.399404	40.95844	78.58286	65.29535	61.61222					
9/14/2004 8:25	4.647222222	111.53	4.09	1096.28	159.00	17982.00	-3.19	7.615587	-3.93	36.890988	2.54	27.584667	40.72169	77.61426	64.48061	60.93885					
9/14/2004 10:15	4.723611111	113.37	4.15	1104.41	160.17	18115.36	-3.16	7.733964	-3.84	37.270005	2.62	27.895043	40.84007	77.99328	64.79099	61.20811					
9/14/2004 16:30	4.984027778	119.62	4.03	1088.15	157.82	17848.63	-3.21	7.536669	-3.97	36.722536	2.51	27.468276	40.64277	77.44581	64.36422	60.8176					
9/15/2004 8:00	5.629861111	135.12	4.02	1086.79	157.62	17826.41	-3.2	7.576128	-4	36.596197	2.53	27.54587	40.68223	77.31947	64.44182	60.8145					
9/15/2004 16:35	5.9875	143.70	4.17	1107.12	160.57	18159.82	-3.11	7.931259	-3.85	37.227892	2.68	28.127825	41.03736	77.95116	65.02377	61.33743					
9/16/2004 8:20	6.64375	159.45	3.97	1080.01	156.64	17715.27	-3.18	7.655046	-4.04	36.427745	2.56	27.662261	40.76115	77.15102	64.55821	60.82346					
9/16/2004 16:35	6.9875	167.70	4.07	1093.57	158.60	17937.54	-3.13	7.852341	-3.95	36.806762	2.63	27.93384	40.95844	77.53003	64.82979	61.10609					
9/17/2004 8:50	7.664583333	183.95	3.86	1065.11	154.48	17470.77	-3.21	7.536669	-4.17	35.880276	2.48	27.351885	40.64277	76.60355	64.24783	60.49805					



Tile Bale 0 Creep at 20 kips Vertical Load

Reading #	Time (hrs)	LC (kPa)	LC (psi)	LC (lbf)	LVDT 3 (mm)	LVDT 4 (mm)	LVDT 5 (mm)	Average (mm)
1	0.000561	28.5841	4.146	468.859	0	0	19.49326	6.497753
10	0.005561	28.5841	4.146	468.859	0.03854	0	0.01894	0.01916
20	0.011122	29.2458	4.242	479.713	0	0	0.03788	0.012627
50	0.027805	115.925	16.813	1901.495	0.05781	0.06169	6.78189	2.300463
100	0.05561	145.038	21.035	2379.030	0.03854	0.14394	12.0104	4.064293
200	0.11122	292.59	42.435	4799.297	0.19268	1.95348	32.20456	11.45024
400	0.22244	494.4	71.704	8109.546	0.65509	7.17648	49.33647	19.05601
500	0.27805	613.5	88.978	10063.120	1.3487	14.59972	62.33196	26.09346
1000	0.5561	1130.93	164.022	18550.423	8.18852	48.23498	94.63786	50.35379
2000	1.1122	1144.82	166.036	18778.258	9.151872	50.70254	99.12756	52.99399
3000	1.6683	1114.38	161.621	18278.957	9.132605	50.59972	98.96211	52.89815
4000	2.2244	1118.35	162.197	18344.076	9.248208	50.90814	98.96211	53.03949
5000	2.7805	1122.99	162.870	18420.185	9.402344	51.21664	99	53.20633
6000	3.3366	1129.6	163.829	18528.608	9.5179469	51.56614	99.01894	53.36768
7000	3.8927	1138.2	165.076	18669.672	9.6142823	51.93634	99.03788	53.5295
8000	4.4488	1105.78	160.374	18137.893	9.5179469	51.48394	99	53.33396
9000	5.0049	1092.55	158.455	17920.884	9.4794127	51.29884	99	53.25942
10000	5.561	1098.5	159.318	18018.481	9.5179469	51.42224	99.03788	53.32602
20000	11.122	1089.9	158.071	17877.416	9.82622	52.05974	99.09472	53.66023
30000	16.683	1127.62	163.542	18496.130	10.192295	53.27294	99.20838	54.22454
40000	22.244	1081.96	156.920	17747.178	10.038158	52.67654	99.15155	53.95542
50000	27.805	1096.52	159.031	17986.003	10.134494	53.06724	99.15155	54.11776
60000	33.366	1072.04	155.481	17584.462	10.134494	52.92334	99.17049	54.07611
70000	38.927	1081.96	156.920	17747.178	10.250096	53.19064	99.20838	54.21637
80000	44.488	1065.42	154.521	17475.876	10.192295	53.04674	99.22732	54.15545
90000	50.049	1059.47	153.658	17378.279	10.153761	52.86164	99.15155	54.05565
100000	55.61	1076.67	156.152	17660.407	10.250096	53.25234	99.20838	54.23694
120000	66.732	1046.89	151.833	17171.932	10.211562	52.96444	99.20838	54.12813
140000	77.854	1093.21	158.551	17931.710	10.500568	54.25994	99.3031	54.68787
160000	88.976	1089.24	157.975	17866.591	10.57764	54.42444	99.35993	54.78734
180000	100.098	1100.49	159.607	18051.122	10.65471	54.75344	99.39782	54.93532
200000	111.22	1068.73	155.001	17530.169	10.5969	54.21884	99.3031	54.70628
250000	139.025	1130.26	163.925	18539.434	11.13638	56.25454	99.77669	55.72254
300000	166.83	1111.08	161.143	18224.828	11.09785	56.06944	99.68198	55.61642
350000	194.635	1087.92	157.784	17844.939	11.07858	55.71994	99.58726	55.46193
400000	222.44	1052.19	152.602	17258.867	10.86664	55.04134	99.41676	55.10825
450000	250.245	1070.71	155.288	17562.647	10.86664	55.26754	99.51148	55.21522
500000	278.05	1040.28	150.875	17063.509	10.73177	54.44504	99.41676	54.86452
550000	305.855	1076.01	156.057	17649.581	11.02078	55.43204	99.81458	55.42247
600000	333.66	1052.85	152.698	17269.692	10.96298	54.83574	99.77669	55.1918
650000	361.465	1017.78	147.611	16694.446	10.82811	54.01314	99.51148	54.78424
700000	389.27	986.021	143.005	16173.509	10.69324	52.71774	99.34099	54.25066
750000	417.075	963.524	139.742	15804.496	10.5969	52.05974	99.3031	53.98658
800000	444.88	955.584	138.591	15674.257	10.55837	51.73064	99.3031	53.86404
850000	472.685	965.509	140.030	15837.055	10.57764	51.71014	99.3031	53.86363
900000	500.49	975.434	141.470	15999.853	10.65471	51.89514	99.32204	53.9573
950000	528.295	953.599	138.303	15641.698	10.5969	51.48394	99.3031	53.79465
1000000	556.1	949.629	137.727	15576.579	10.57764	51.27834	99.28415	53.71338
1050000	583.905	954.26	138.399	15652.540	10.67397	51.50454	99.32204	53.83352
1100000	611.71	953.599	138.303	15641.698	10.67397	51.40164	99.32204	53.79922
1150000	639.515	970.802	140.798	15923.875	10.71251	51.79234	99.35993	53.95493
1200000	667.32	964.185	139.838	15815.338	10.73177	51.83354	99.37887	53.98139
1250000	695.125	979.404	142.046	16064.972	10.78957	51.83354	99.39782	54.00698
1300000	722.93	1091.23	158.264	17899.232	11.44466	54.15714	101.974181	55.85866
1350000	750.735	1084.61	157.304	17790.646	11.59879	53.74584	102.694047	56.01289
1400000	778.54	1069.39	155.096	17540.995	11.67586	53.60194	102.542496	55.9401
1450000	806.345	1082.62	157.015	17758.004	11.79146	53.70474	103.205531	56.23391
1500000	834.15	1074.68	155.864	17627.766	11.79146	53.54024	103.413913	56.24854
1550000	861.955	1057.48	153.369	17345.637	11.79146	53.12894	103.016092	55.97883
1600000	889.76	1038.95	150.682	17041.694	11.75293	52.57374	102.353058	55.55991
1650000	917.565	1005.87	145.884	16499.089	11.59879	51.81294	101.12171	54.84448
1700000	945.37	924.485	134.080	15164.147	11.30979	49.71551	99.85247	53.62592
1750000	973.175	924.485	134.080	15164.147	11.30979	49.57157	99.79564	53.559
1800000	1000.98	851.701	123.524	13970.285	11.19418	46.56938	99.41676	52.39344
1850000	1028.785	29.2458	4.242	479.713	0.05781	43.64943	73.28818	38.99847
1900000	1056.59	33.2158	4.817	544.832	0.03854	43.54662	74.23537	39.27351
1950000	1084.395	20.6441	2.994	338.621	-0.09633	17.95144	72.09472	29.98328
1989000	1106.0829	19.9824	2.898	327.767	-0.07706	17.76644	72.01894	29.90277

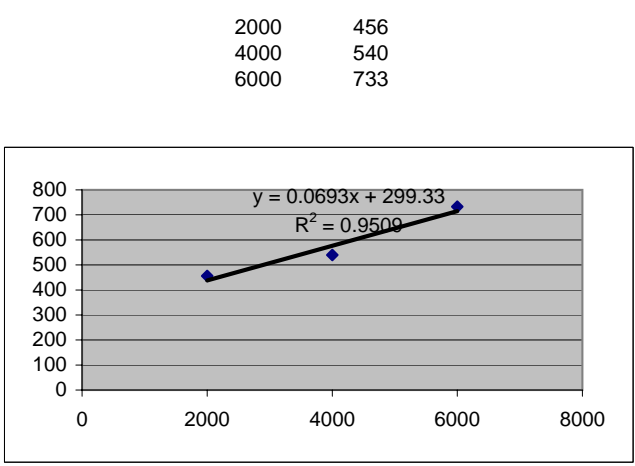
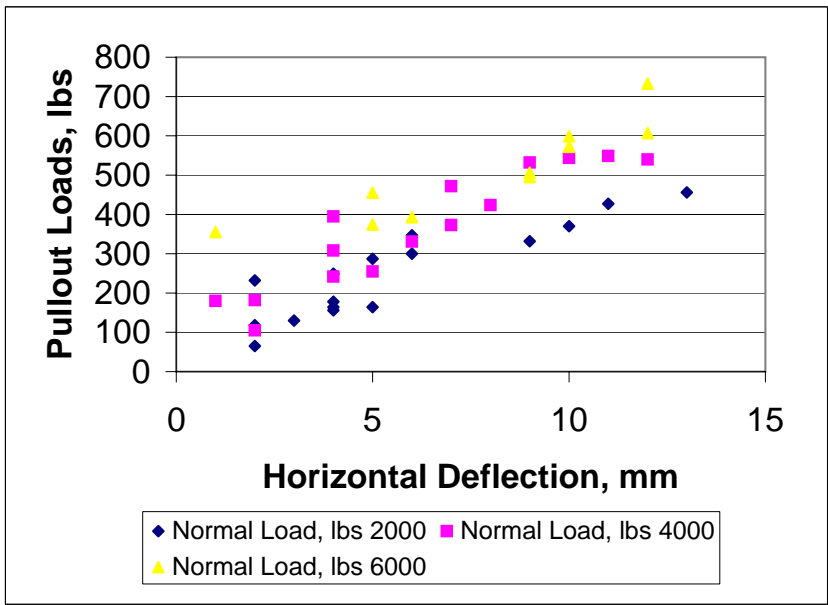
Tile Bale 0 Creep at 20 kips Vertical Load



Pull Out Test

Project No. : GTX-G0581 Test By: JW, SS, & HJ
 Project Name: Tire Bale Study Test Date: 9/3/2004
 Tire Bale No.: 3

Normal Load, lbs 2000					Normal Load, lbs 4000					Normal Load, lbs 6000				
Loads		Horizontal Deflection			Loads		Horizontal Deflection			Loads		Horizontal Deflection		
Initial (lbs)	Final (lbs)	Increment (lbs)	Total (mm)	Increment (mm)	Initial (lbs)	Final (lbs)	Increment (lbs)	Total (mm)	Increment (mm)	Initial (lbs)	Final (lbs)	Increment (lbs)	Total (mm)	Increment (mm)
90	155	65	2	2	204	384	180	1	1	245	600	355	3	1
144	262	118	4	2	334	439	105	3	2	540	914	374	8	5
207	337	130	7	3	420	602	182	5	2	824	1217	393	14	6
244	408	164	11	4	510	752	242	9	4	1097	1552	455	19	5
342	498	156	15	4	634	889	255	14	5	1404	1899	495	28	9
450	614	164	20	5	787	1095	308	18	4	1724	2230	506	37	9
532	710	178	24	4	964	1295	331	24	6	2079	2651	572	47	10
617	849	232	26	2	1145	1540	395	28	4	2405	3004	599	57	10
760	1009	249	30	4	1394	1767	373	35	7	2800	3407	607	69	12
895	1195	300	36	6	1600	2024	424	43	8	3209	3942	733	81	12
1052	1339	287	41	5	1847	2319	472	50	7					
1205	1552	347	47	6	2130	2662	532	59	9					
1394	1726	332	56	9	2340	2889	549	70	11					
1572	1942	370	66	10	2580	3124	544	80	10					
1752	2179	427	77	11	2922	3462	540	92	12					
1857	2313	456	90	13										



Project No : GTX G0581
Tested By: HJ, SD, DC & JW
Test Date: 12/16/2004 - 12/27/04

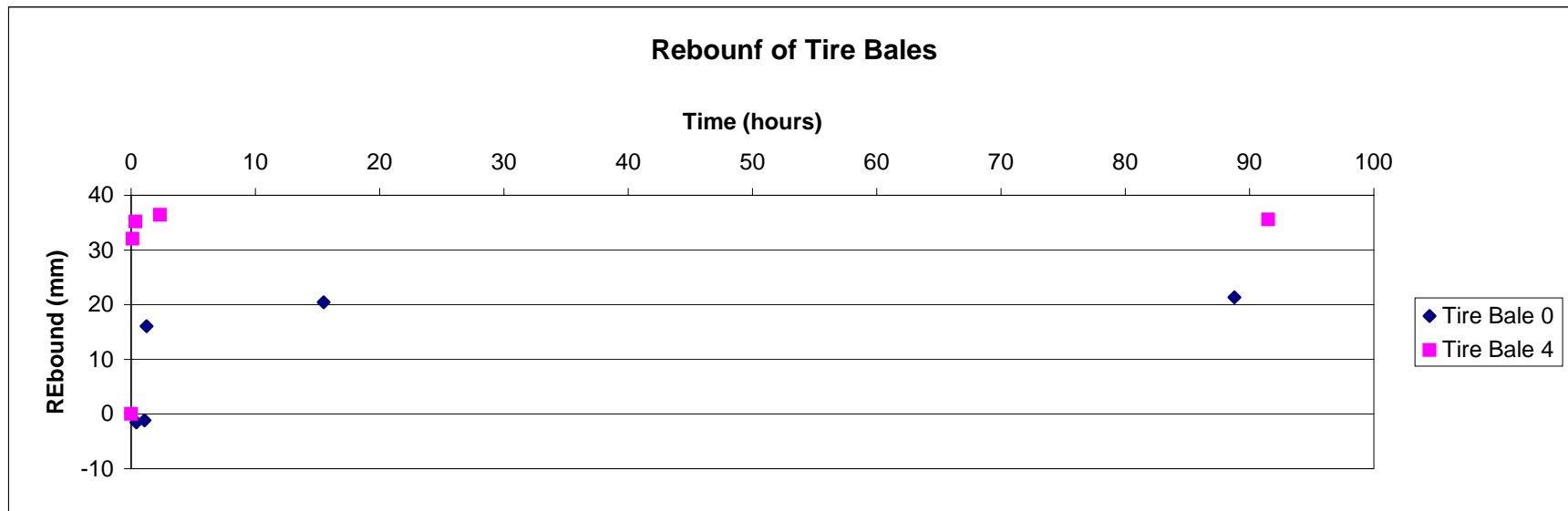
Project Name: Tire Bale Study
Reviewed By: JW
Review Date: _____

Tire Bale 0

Date/Time	Elapsed Time (hour)										Average Swell (mm)					
		(voltage)	(mm)	Swell (mm)	(voltage)	(mm)	Swell (mm)	(voltage)	(mm)	Swell (mm)		voltage	kPa	kPa	psi	lbs
12/16/04 15:35	0.00	-2.13	5.9	0.0	1.55	24.7	0.0	3.2	30.3	0.0	0.0	-3.76	32.5	0.0	0.0	0.0
12/16/04 16:00	0.42	-2.15	5.8	0.1	2.36	28.1	-3.4	3.48	31.5	-1.2	-1.5	-3.61	52.8	20.3	3.0	333.7
12/16/04 16:40	1.08	-2.15	5.8	0.1	2.4	28.3	-3.6	3.18	30.2	0.1	-1.1	-3.6	54.2	21.7	3.1	355.9
Release of the vertical load											Swell Presuure= 60.3 psi					
12/16/04 16:50	1.25	-3.72	-0.4	6.3	-0.37	16.6	8.1	-4.72	-3.6	33.9	16.1					
12/17/04 7:05	15.50	-4.7	-4.3	10.1	-2	9.7	15.0	-5.26	-5.9	36.2	20.4					
12/20/04 8:22	88.78	-4.83	-4.8	10.7	-2.55	7.4	17.3	-5.25	-5.9	36.2	21.4					

Tire Bale 4

12/23/04 14:00	0.00	-5.9	-9.0	0.0	-5.23			-5.15	-6.0	0.0	0
12/23/04 14:07	0.12	0.67	16.9	25.9	LVDT was pushed out			-2.05	6.2	12.2	32.04071
12/23/04 14:21	0.35	1.28	19.3	28.3				-1.68	7.7	13.7	35.1777
12/23/04 16:20	2.33	1.36	19.7	28.6				-1.2	9.5	15.6	36.44039
12/27/04 9:30	91.50	0.79	17.4	26.4				-0.5	12.3	18.3	35.57229



Unconfined Compression of Tire Bales

a study performed at the Georgia Institute of Technology

The objective of this experimental investigation was to find the vertical and circumferential deformations resulting from a vertical compression load for three tire bales. Following is a report on the four tests conducted. The first two tests were conducted on tire bale No. 7, and the next two on tire bales Nos. 2 and 8. All data are presented in the Appendix. Load versus Vertical and Circumferential graphs are given in the main body of the report.

Test Setup

A structural steel frame with columns forming an eight foot square was positioned and posttensioned to the concrete structural test floor. Two square concrete platens measuring 66" wide by 20" deep were used for top and bottom load bearing surfaces positioned in the middle of the steel frame as shown in Figure 1. In the first test it was found that the top platen was over rotating due to the non-uniformity of the tire bale. The problem was mitigated by attaching outriggers to all four sides of the top platen. A 1000 kip actuator was positioned in the center of the columns and applied the load to the top platen which distributed the load evenly to the tire bale. A 700 kip load cell was attached to the actuator to measure the applied load. Four 40-in. string potentiometers were positioned at the corners to measure vertical deformation. Vertical deformation at the corners also was measured using a measuring tape accurate to 1/16-inch. The circumference was measured by hand using a flexible metal measuring tape threaded through eye hooks around the middle of the tire bales to ensure consistency of measurements. Measurements were taken every 10 kips through 100 kips and then every 25 kips thereafter.



Figure 1: Test setup

Test Results: Tire Bale #7, Test No. 1

Test No.1 on Tire bale #7 was conducted on March 24th. Bale dimensions were recorded as well as vertical displacements at the four corners of the platen and circumference was taken at the middle and top and bottom quarter heights. Initial dimensions are given in Table 1. Figure 2 shows the initial test setup. Figures 3 through 5 present load versus vertical and circumferential graphs.

Table 1: Initial dimensions of Tire Bale # 7

Date	3/24/2004
Tire Bale #	7
Test #	1

	Dimensions (in)				Average
Height	30.875	31.875	30.063	32.625	31.359
Length	65.500	63.750			64.625
Width	61.000	60.750			60.875



Figure 2: Tire Bale # 7, Test # 1

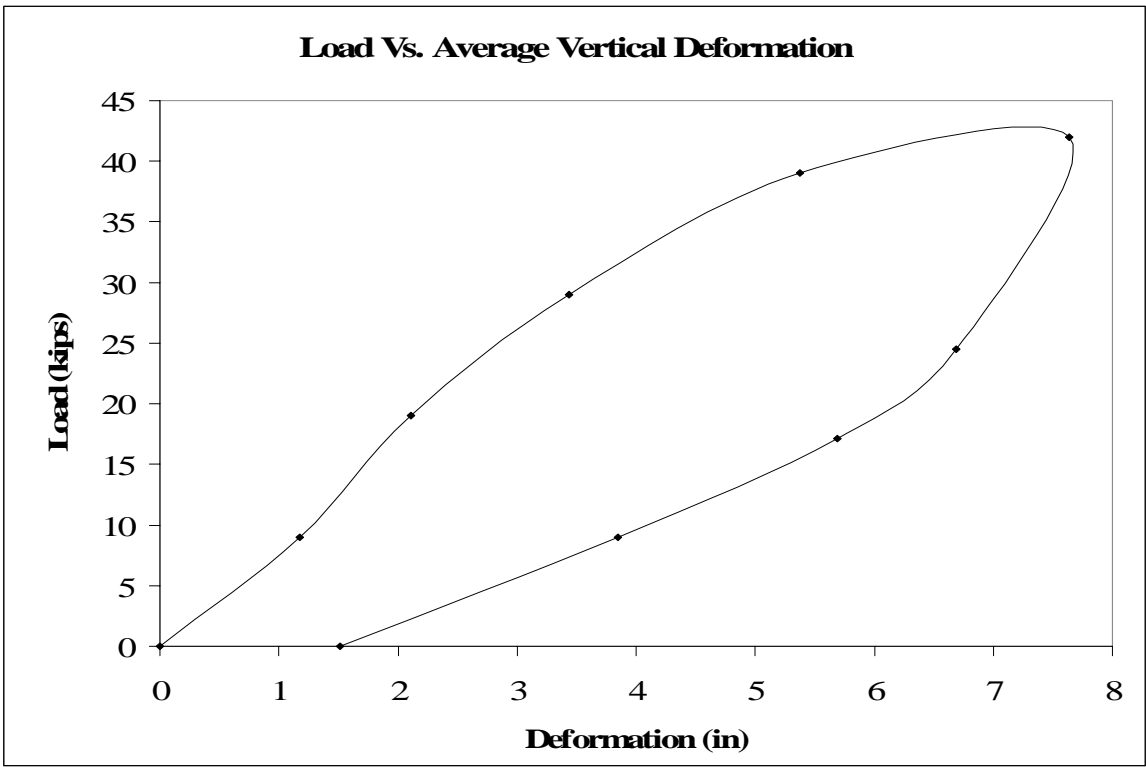


Figure 3: Tire Bale #7, Test No.1, Load vs. Average Vertical Deformation

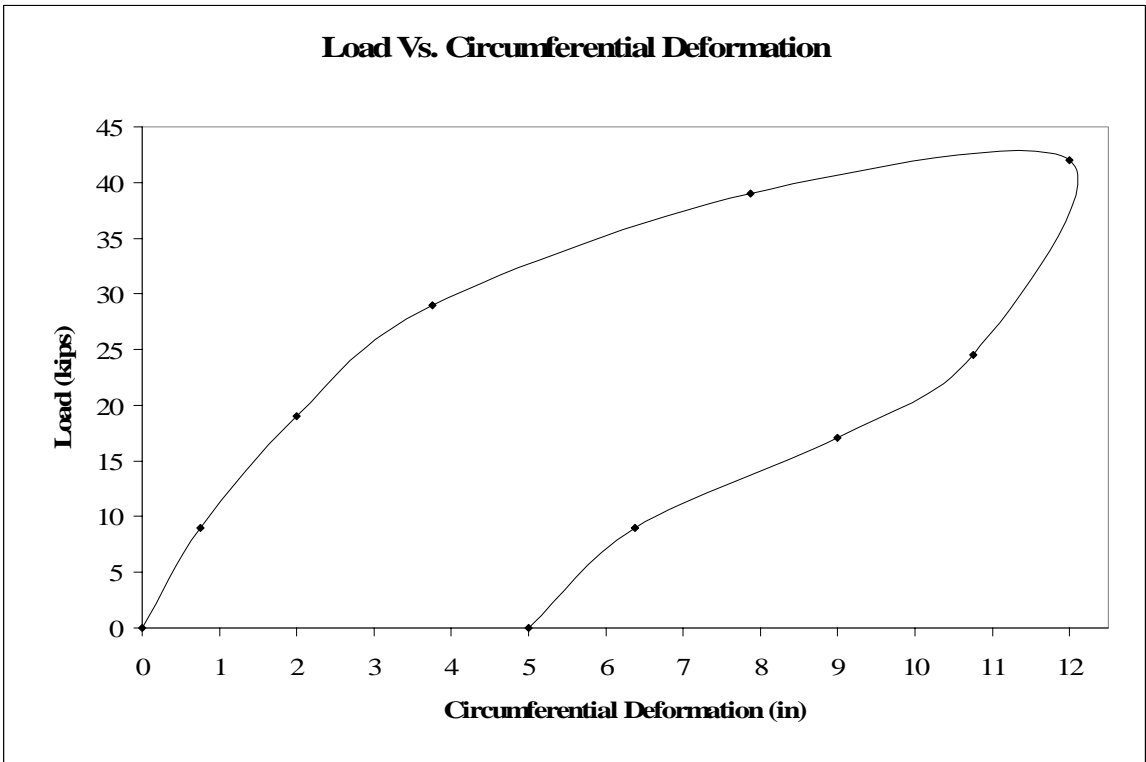


Figure 4: Tire Bale #7, Test No.1, Load vs. Circumferential Deformation

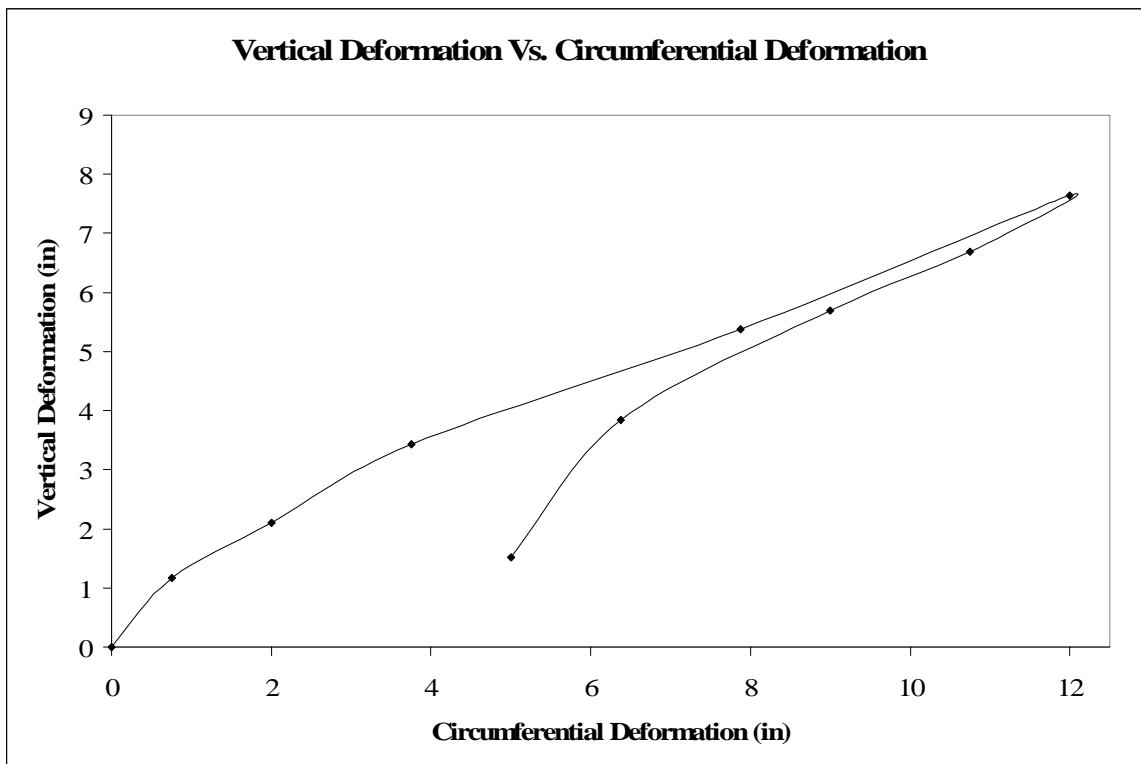


Figure 5: Tire Bale #7, Test No.1, Vertical Deformation vs. Circumferential Deformation

Test # 1 on Tire Bale #7 loaded the bale to 42 kips, where it was observed that the platen rotated and would have to be supported to inhibit that rotation.

Test Results: Tire Bale #7, Test #2

Test #2 was conducted on May 24th on Tire bale #7. Bale dimensions were recorded as well as vertical displacements at the four corners of the platen and the circumference was taken at the middle. Circumferential measurements were only taken at the middle due to the inaccuracy of the results from Test # 1 at the top and bottom quarter heights. Initial dimensions are given in Table 2. Figure 6 shows the test setup. Figures 7 through 9 present load versus vertical and circumferential graphs.

Table 2: Initial dimensions of Tire Bale # 7

Date	5/24/2004
Tire Bale #	7
Test #	2

	Dimensions (in)				Average
Height	30.188	30.250	30.500	30.375	30.328
Length	65.500	63.750			64.625
Width	61.000	60.750			60.875



Figure 6: Circumferential measurements. Outriggers mitigated rotation problem.

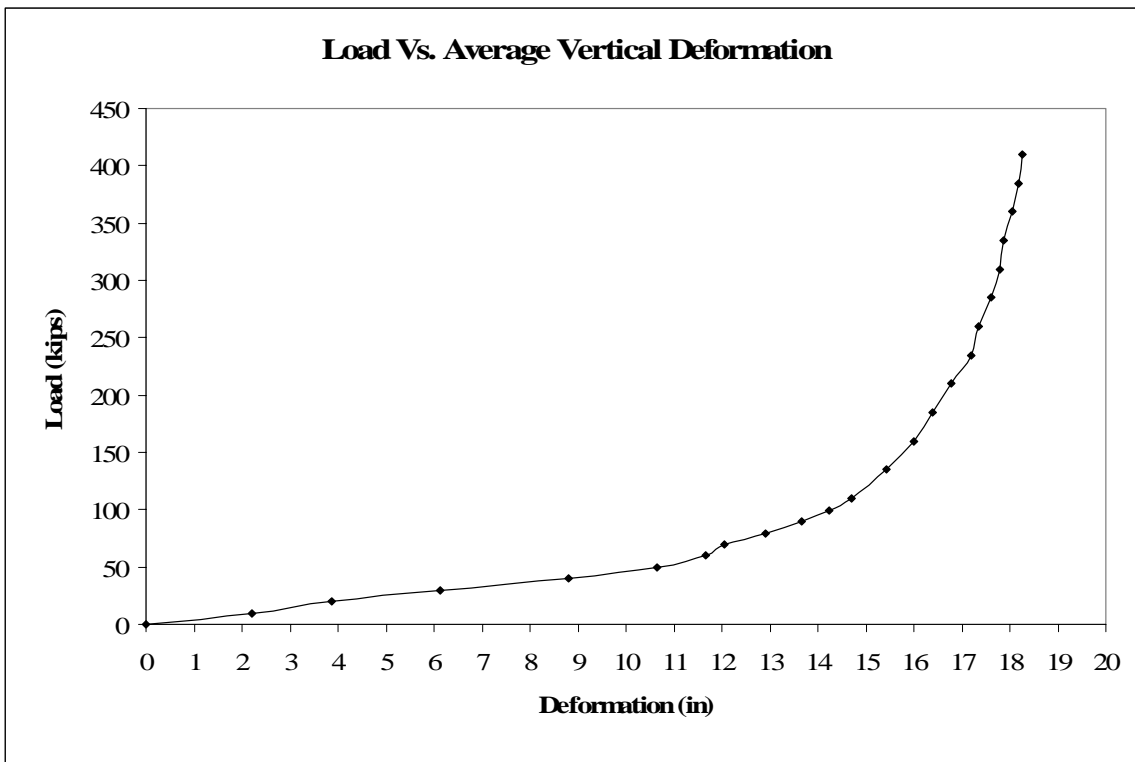


Figure 7: Tire Bale #7, Test No.2, Load vs. Average Vertical Deformation

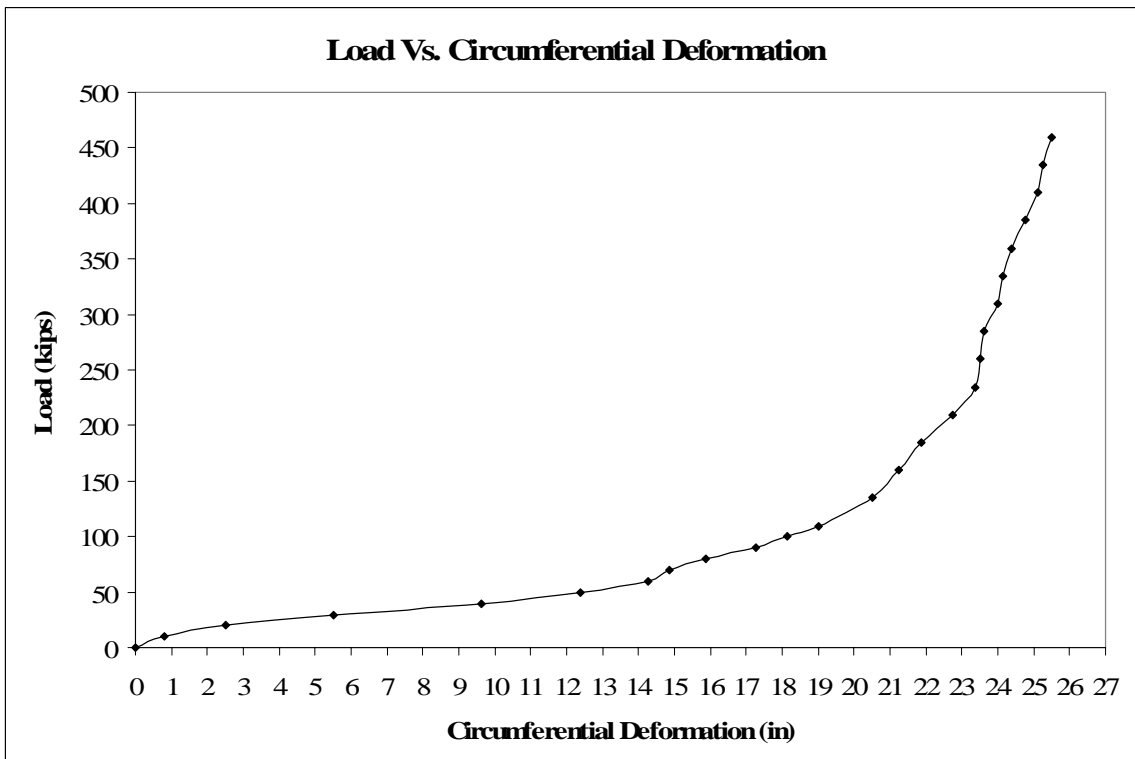


Figure 8: Tire Bale #7, Test No.2, Load vs. Circumferential Deformation

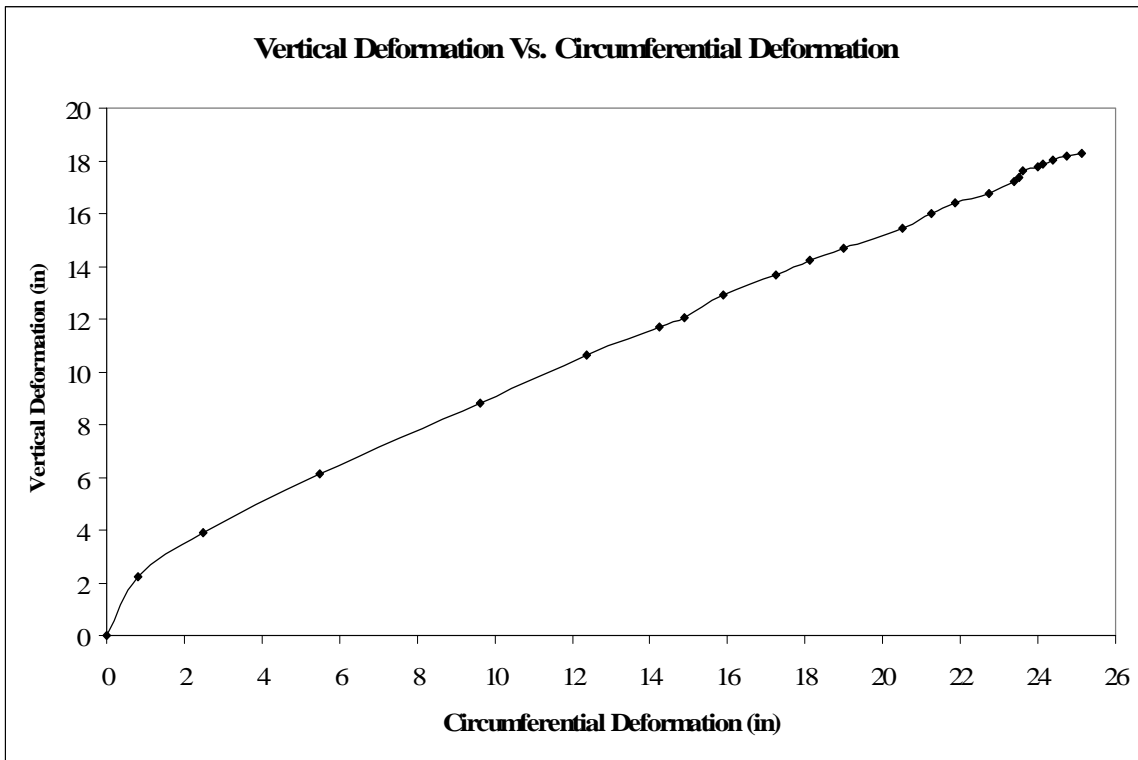


Figure 9: Tire Bale #7, Test No.2, Vertical Deformation vs. Circumferential Deformation

The second test on Tire Bale # 7 loaded the bale to 460 kips. Two of the bale’s metal wires broke above 400 kips. Bale # 7 had a permanent vertical deformation of 1.2 in. and a permanent circumferential deformation of 7.75 in.

Test Results: Tire Bale #2

Tire Bale # 2 was tested on July 21st. Bale dimensions were recorded as well as vertical displacements at the four corners of the platen and circumference was taken at the middle. Initial dimensions are given in Table 3. Figure 10 shows Tire Bale #2 loaded to 500 kips. Figures 11 through 13 present load versus vertical and circumferential graphs.

Table 3: Initial dimensions of Tire Bale # 2

Date	7/21/2004
Tire Bale #	2

	Dimensions (in)				Average
Height	34.125	33.8125	34.5625	33.8125	34.08
Length	68.25	62.875			65.56
Width	62.1875	60.5			61.34

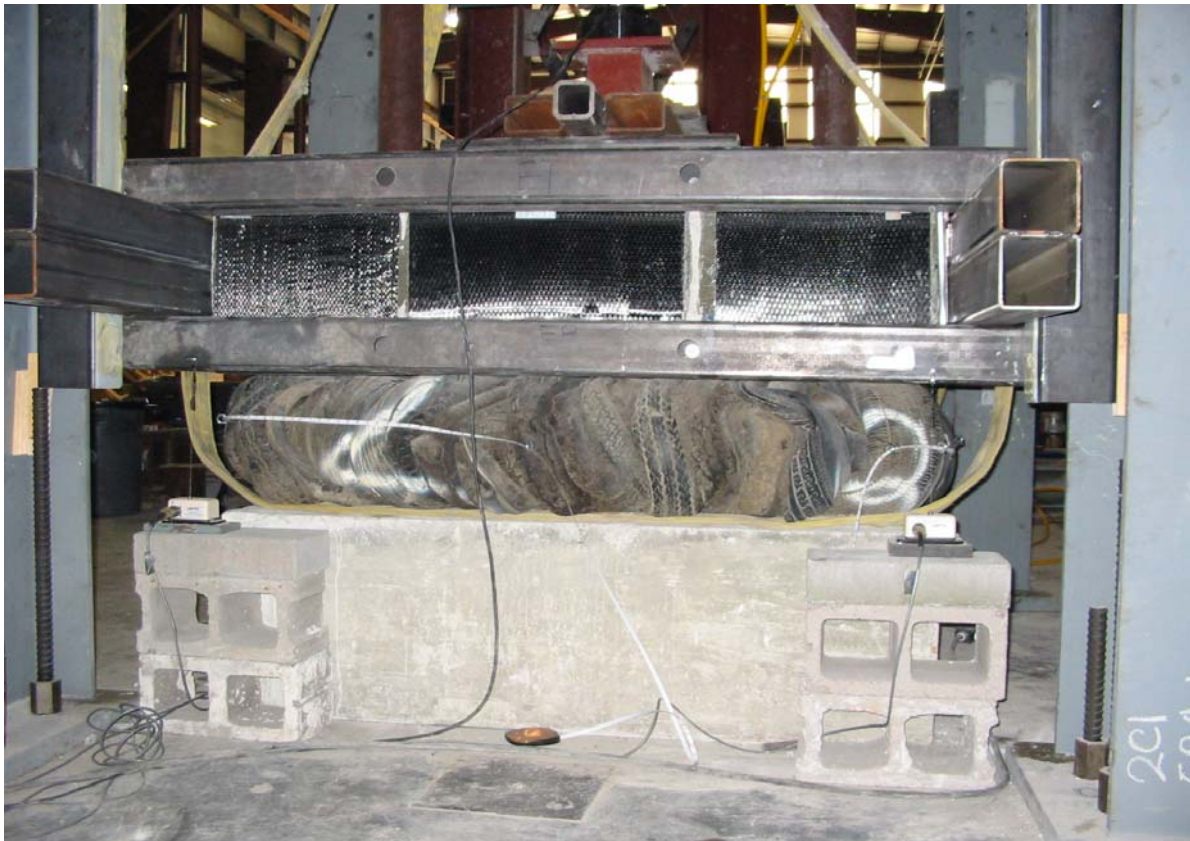


Figure 10: Tire Bale # 2 loaded to 500 kips

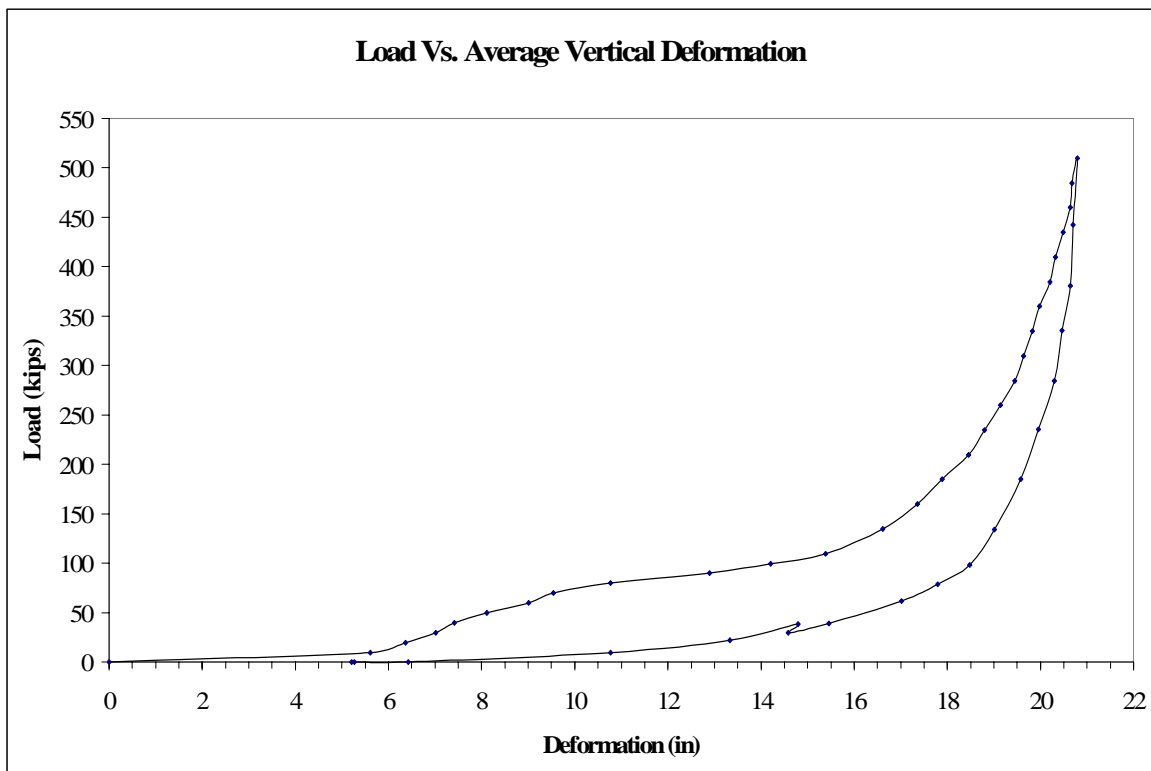


Figure 11: Tire Bale #2, Load vs. Average Vertical Deformation

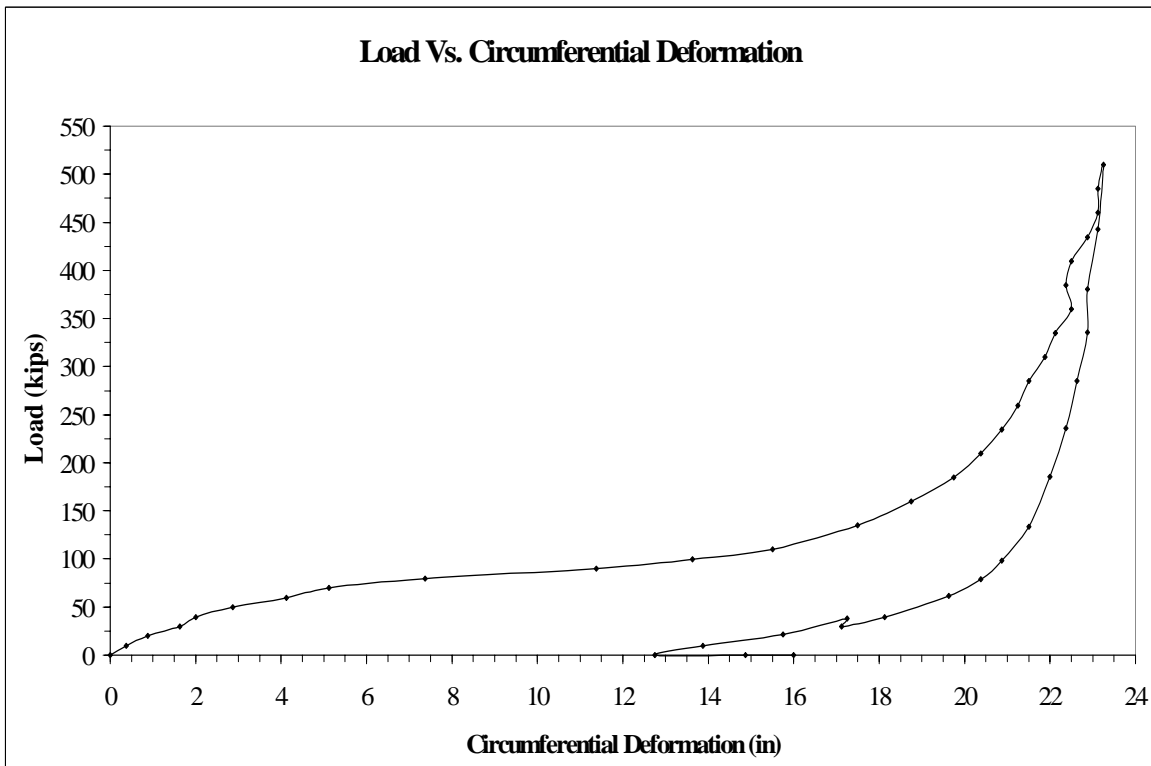


Figure 12: Tire Bale #2, Load vs. Circumferential Deformation

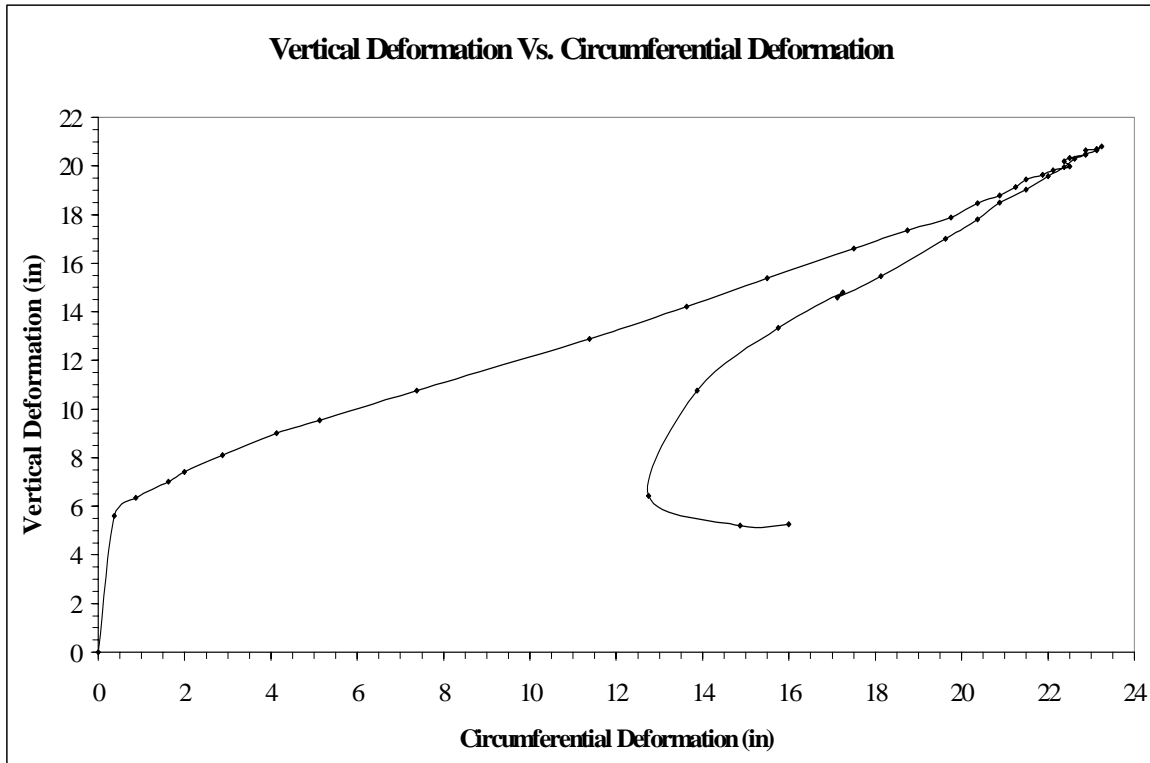


Figure 13: Tire Bale #2, Vertical Deformation vs. Circumferential Deformation

Tire Bale # 2 was loaded to 510 kips. Two of the bale’s metal wires broke. Bale # 2 underwent 5.3 in. of permanent vertical deformation and 16 in. of permanent circumferential deformation.

Test Results: Tire Bale #8

Tire Bale # 8 was tested on July 22nd. Bale dimensions were recorded as well as vertical displacements at the four corners of the platen and circumference was taken at the middle. Initial dimensions are given in Table 4. Figure 14 shows Tire Bale #8 loaded to 592 kips. Figures 15 through 17 present load versus vertical and circumferential graphs.

Table 4: Initial dimensions of Tire Bale # 8

Date	7/22/2004
Tire Bale#	8

	Dimensions (in)				Average
Height	31.5	32	31.875	31.5	31.72
Length	67.5	64			65.75
Width	61	61.5			61.25



Figure 14: Tire Bale # 8 loaded to 592 kips

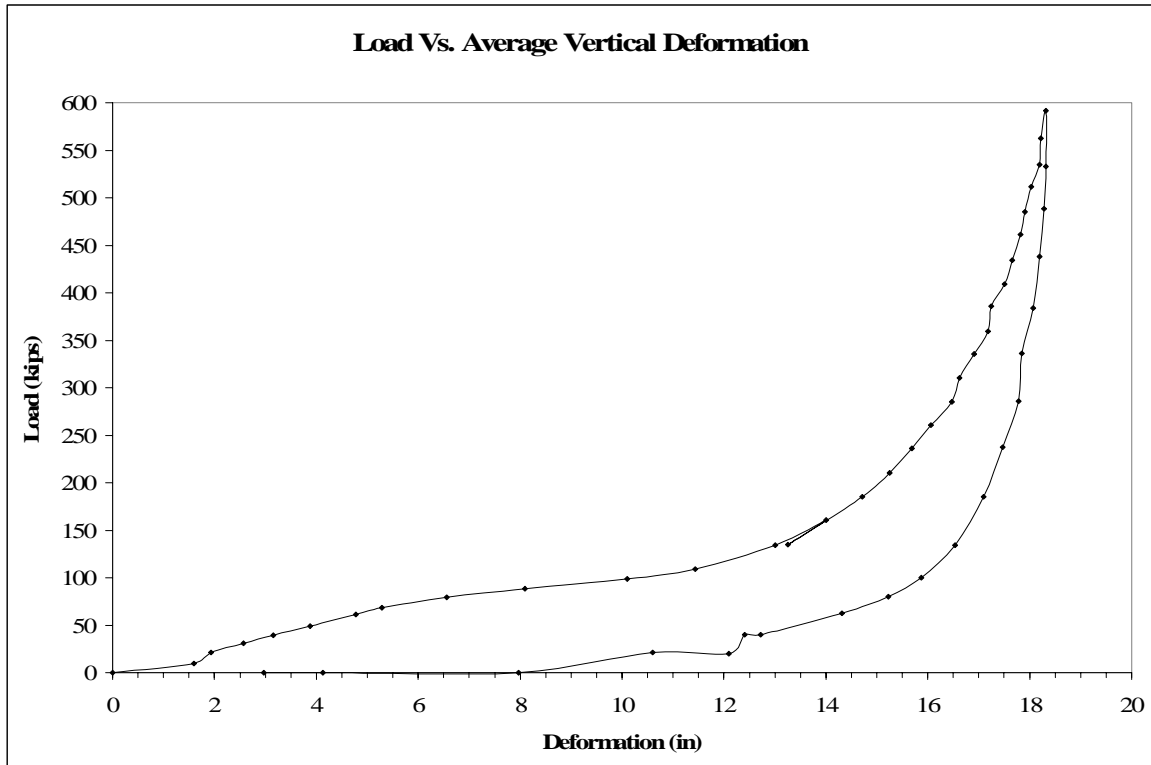


Figure 15: Tire Bale #8, Load vs. Average Vertical Deformation

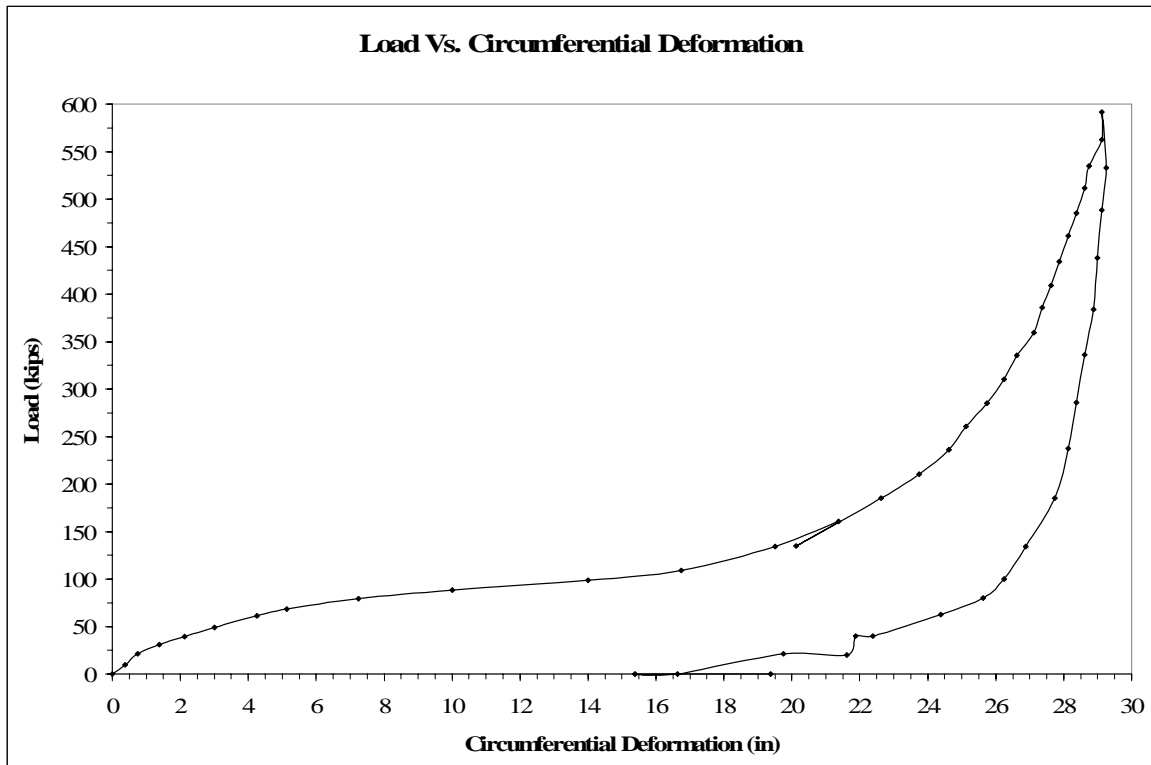


Figure 16: Tire Bale #8, Load vs. Circumferential Deformation

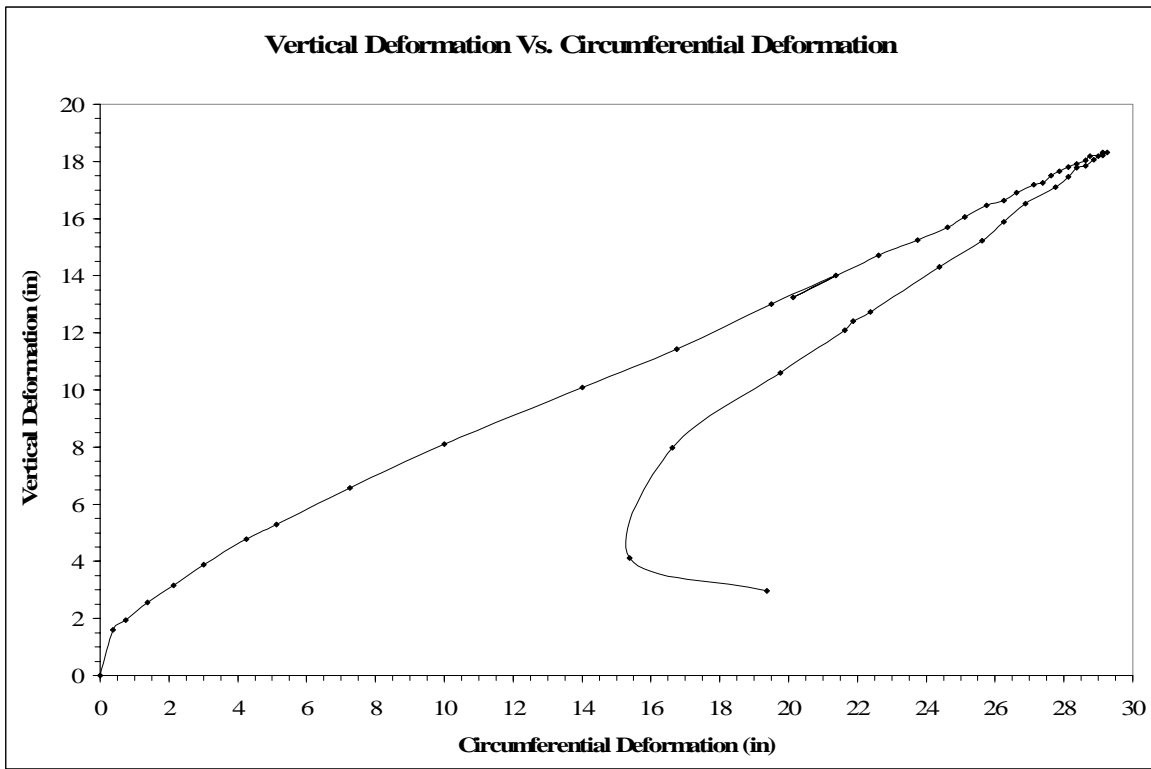


Figure 17: Tire Bale #2, Vertical Deformation vs. Circumferential Deformation

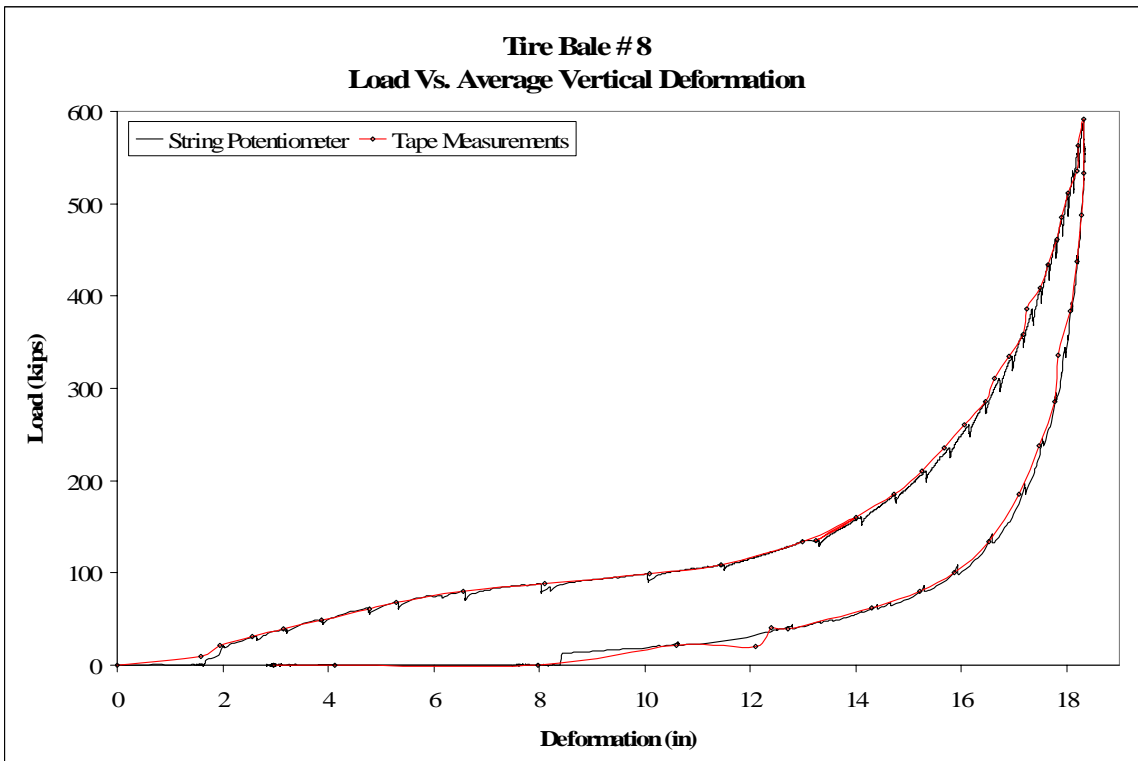
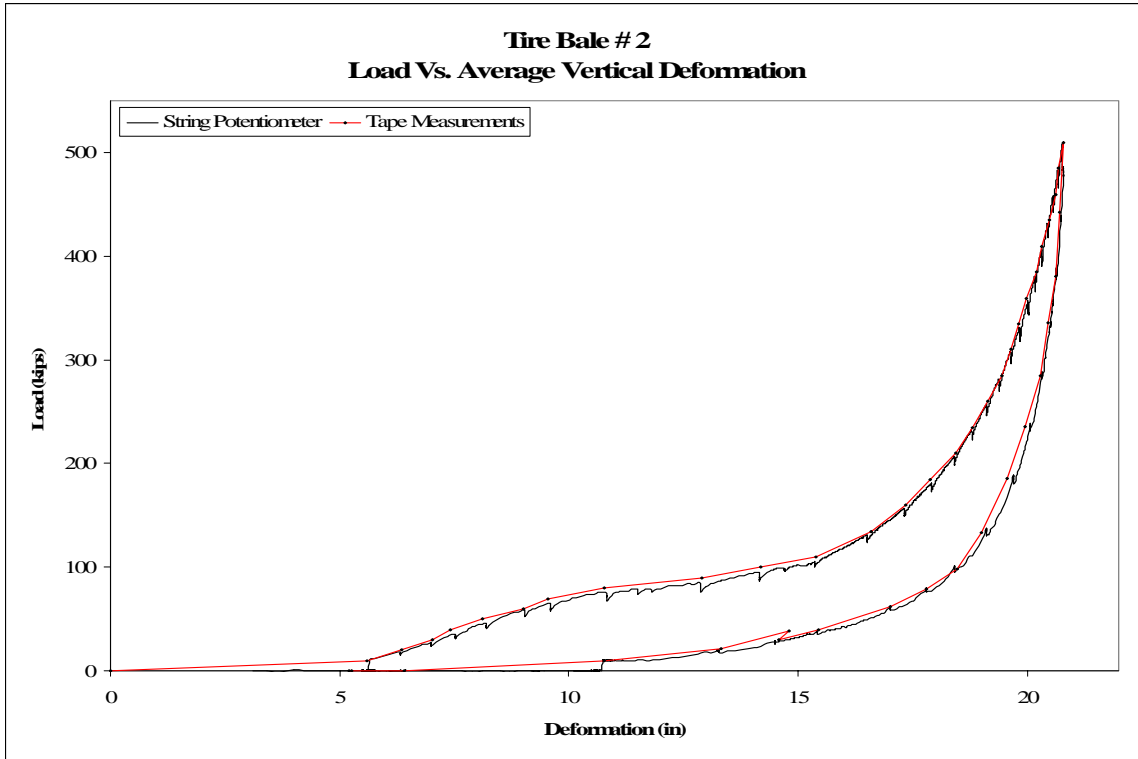
Tire Bale # 8 was loaded to 592 kips. Metal wires broke at 62 kips and 175 kips. Bale # 8 underwent 3 in. of permanent vertical deformation and 19.4 in. of permanent circumferential deformation.

Appendix: Experimental Data

Date	3/24/2004								
Tire Bale #	7								
Test #	1								
Dimensions (in)						Average			
Height	30.875	31.875	30.063	32.625	31.359				
Width	65.500	63.750			64.625				
Length	61.000	60.750			60.875				
Load (kips)			Deformation (in)						
Applied	Actual	Vert 1	Vert 2	Vert 3	Vert 4	Average Vertical	CircumBot	CircumMid	CircumTop
w/o Platten	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
w/ Platten	9	1.500	0.875	-0.188	2.500	1.172	0.250	0.750	0.500
10	19	2.438	1.875	0.625	3.500	2.109	5.750	2.000	0.375
20	29	3.750	3.125	2.063	4.813	3.438	10.500	3.750	4.875
30	39	5.500	5.375	4.188	6.438	5.375	13.625	7.875	8.000
33	42	6.250	8.875	8.000	7.438	7.641	13.875	12.000	11.750
15.5	24.5	5.375	7.938	6.813	6.625	6.688	12.125	10.750	11.250
8.1	17.1	4.625	6.688	5.688	5.750	5.688	10.875	9.000	10.250
w/ Platten	9	3.813	3.750	2.813	5.000	3.844	7.000	6.375	4.250
w/o Platten	0	2.063	1.875	0.313	1.813	1.516	5.000	5.000	-2.875
w/o Platten	0						5.000	0.000	-1.500
w/o Platten	0						0.25	0.75	0.5
Date	5/24/2004								
Tire Bale #	7								
Test #	2								
Dimensions (in)						Average			
Height	30.188	30.250	30.500	30.375	30.328				
Width	65.5	63.75			64.625				
Length	61.0	60.75			60.875				
Load (kips)			Deformation (in)						
Applied	Actual	Vert 1	Vert 2	Vert 3	Vert 4	Average Vertical	CircumMid		
w/o Platten	0.0	0	0	0	0	0.00	0.00		
w/ Platten	9.7	2.9375	1.625	1.5	2.75	2.20	0.81		
10	19.7	4.6875	3.375	3.125	4.3125	3.88	2.50		
20	29.7	6.9375	5.625	5.375	6.5625	6.13	5.50		
30	39.7	9.8125	8.375	7.875	9.125	8.80	9.63		
40	49.7	11.6875	10.25	9.625	11.0625	10.66	12.38		
50	59.7	12.4375	11.375	10.75	12.125	11.67	14.25		
60	69.7	12.5625	12.1875	11.375	12.125	12.06	14.88		
70	79.7	13.6875	12.875	12.25	12.875	12.92	15.88		
80	89.7	14.375	13.625	13	13.625	13.66	17.25		
90	99.7	14.9375	14.25	13.5	14.25	14.23	18.13		
100	109.7	15.4375	14.6875	14	14.6875	14.70	19.00		
125	134.7	16.1875	15.5	14.5	15.5625	15.44	20.50		
150	159.7	16.8125	15.9375	15.25	16	16.00	21.25		
175	184.7	17.1875	16.25	15.5	16.625	16.39	21.88		
200	209.7	17.6875	16.625	15.75	17.0625	16.78	22.75		
225	234.7	18.1875	16.875	16.25	17.5	17.20	23.38		
250	259.7	18.1875	17	16.5	17.6875	17.34	23.50		
275	284.7	18.4375	17.25	16.75	18	17.61	23.63		
300	309.7	18.6875	17.375	16.75	18.375	17.80	24.00		
325	334.7	18.9375	17.375	16.75	18.4375	17.88	24.13		
350	359.7	19.1875	17.5	16.875	18.625	18.05	24.38		
375	384.7	19.1875	17.8125	16.875	18.875	18.19	24.75		
400	409.7	19.4375	17.625	17	19	18.27	25.13		
425	434.7						25.25		
450	459.7						25.50		
w/o platten	0	1.1875	0.875	1.125	1.5625	1.19	7.75		

Date	7/21/2004						
Tire Bale#	2						
Load (kips)		Deformation (in)					
Measured	Actual	Vert 1	Vert 2	Vert3	Vert 4	Average	Circum
w/o platen	0	0	0	0	0	0.00	0
w/platen	9.72	5.75	4.8125	6.0625	5.8125	5.61	0.375
10	19.72	6.375	5.5625	6.6875	6.8125	6.36	0.875
20	29.72	7	6.1875	7.3125	7.5625	7.02	1.625
30	39.72	7.5	6.5625	7.5625	8.0625	7.42	2
40	49.72	8.25	7.3125	8.3125	8.5625	8.11	2.875
50	59.72	9.125	8.0625	9.1875	9.6875	9.02	4.125
60	69.72	9.625	8.5625	9.6875	10.3125	9.55	5.125
70	79.72	10.875	9.8125	11.0625	11.3125	10.77	7.375
80	89.72	12.875	12.0625	13.3125	13.3125	12.89	11.375
90	99.72	14.125	13.3125	15.0625	14.3125	14.20	13.625
100	109.72	15.125	14.5625	16.3125	15.5625	15.39	15.5
125	134.72	16.125	15.8125	17.5625	16.9375	16.61	17.5
150	159.72	17	16.6875	18.3125	17.4375	17.36	18.75
175	184.72	17.625	17.3125	18.8125	17.8125	17.89	19.75
200	209.72	18.125	17.8125	19.3125	18.5625	18.45	20.375
225	234.72	18.5	18.1875	19.5625	18.9375	18.80	20.875
250	259.72	18.75	18.5625	19.9375	19.3125	19.14	21.25
275	284.72	19.125	18.8125	20.3125	19.5625	19.45	21.5
300	309.72	19.25	18.9375	20.5625	19.8125	19.64	21.875
325	334.72	19.5	19.0625	20.8125	19.9375	19.83	22.125
350	359.72	19.625	19.3125	20.9375	20.0625	19.98	22.5
375	384.72	19.875	19.5625	21.0625	20.3125	20.20	22.375
400	409.72	20	19.6875	21.1875	20.4375	20.33	22.5
425	434.72	20.125	19.8125	21.3125	20.6875	20.48	22.875
450	459.72	20.25	19.9375	21.5625	20.8125	20.64	23.125
475	484.72	20.25	20.0625	21.5625	20.8125	20.67	23.125
500	509.72	20.375	20.0625	21.6875	21.0625	20.80	23.25
433	442.56	20.375	20.0625	21.5625	20.8125	20.70	23.125
371	380.55	20.25	19.9375	21.5625	20.8125	20.64	22.875
326	335.59	20.125	19.75	21.4375	20.5625	20.47	22.875
275	284.75	19.875	19.5625	21.1875	20.5625	20.30	22.625
226	235.60	19.625	19.4375	20.6875	20.0625	19.95	22.375
176	185.29	19.375	18.9375	20.4375	19.5625	19.58	22
124	133.75	18.75	18.3125	19.9375	19.0625	19.02	21.5
89	98.48	18.125	17.6875	19.5625	18.5625	18.48	20.875
69	78.80	17.625	17.1875	18.5625	17.8125	17.80	20.375
52	61.71	16.875	16.4375	17.8125	16.9375	17.02	19.625
30	39.26	15.125	14.8125	16.5625	15.3125	15.45	18.125
20	29.50	14.375	13.8125	15.5625	14.5625	14.58	17.125
29	38.26	14.5	14.0625	15.8125	14.8125	14.80	17.25
12	21.74	13.125	12.6875	14.3125	13.1875	13.33	15.75
w/ platen	9.72	10.75	10.3125	11.8125	10.1875	10.77	13.875
w/o platen	0	6	6.3125	7.0625	6.3125	6.42	12.75
w/o platen	0	5.375	4.8125	5.5625	5.0625	5.20	14.875
w/o platen	0	5.5	4.8125	5.5625	5.1875	5.27	16

Date	7/22/2004						
Tire Bale#	8						
Load (kips)		Deformation (in)					
Measured	Actual	Vert 1	Vert 2	Vert3	Vert 4	Average	Circum
w/o platen	0	0	0	0	0	0.00	0
w/platen	9.72	1	2.25	1.875	1.25	1.59	0.375
11.6	21.3	1.5	2.5	2.125	1.625	1.94	0.75
21.0	30.7	2.25	3	2.625	2.375	2.56	1.375
29.5	39.3	2.75	3.5	3.375	3	3.16	2.125
39.6	49.3	3.5	4.125	4.125	3.75	3.88	3
51.8	61.5	4.375	4.875	5.125	4.75	4.78	4.25
58.6	68.3	5	5.375	5.375	5.375	5.28	5.125
69.8	79.5	6.5	6.5	6.625	6.625	6.56	7.25
78.4	88.1	8.125	7.875	8.25	8.125	8.09	10
89.2	99.0	10.125	9.875	10.125	10.25	10.09	14
99.1	108.8	11.5	11.25	11.375	11.625	11.44	16.75
124.7	134.4	13	12.875	13	13.125	13.00	19.5
151.0	160.7	13.875	14	14	14.125	14.00	21.375
125.2	134.9	13.125	13.25	13.375	13.25	13.25	20.125
175.6	185.3	14.5	14.75	14.875	14.75	14.72	22.625
200.4	210.2	15.125	15.25	15.375	15.25	15.25	23.75
226.1	235.8	15.5	15.75	15.875	15.625	15.69	24.625
250.7	260.4	15.875	16.125	16.25	16	16.06	25.125
275.7	285.4	16.25	16.5	16.625	16.5	16.47	25.75
300.5	310.3	16.5	16.625	16.875	16.5	16.63	26.25
325.5	335.2	16.75	17	17	16.875	16.91	26.625
349.4	359.1	17	17.125	17.375	17.25	17.19	27.125
375.8	385.6	17.125	17.25	17.375	17.25	17.25	27.375
399.4	409.1	17.375	17.5	17.75	17.375	17.50	27.625
424.7	434.5	17.5	17.625	17.875	17.625	17.66	27.875
451.5	461.2	17.5	17.75	18	18	17.81	28.125
475.6	485.3	17.75	17.875	18.25	17.75	17.91	28.375
502.0	511.7	17.75	18	18.375	18	18.03	28.625
525.4	535.2	18	18	18.375	18.375	18.19	28.75
552.9	562.6	18	18.125	18.375	18.375	18.22	29.125
582.1	591.9	18.125	18.25	18.375	18.5	18.31	29.125
523.4	533.1	18.25	18.25	18.25	18.5	18.31	29.25
478.5	488.2	18.125	18.25	18.25	18.5	18.28	29.125
428.2	438.0	18	18.125	18.25	18.375	18.19	29
374.2	384.0	17.875	18	18.125	18.25	18.06	28.875
326.3	336.0	17.75	17.875	17.875	17.875	17.84	28.625
276.3	286.0	17.625	17.75	17.75	18	17.78	28.375
227.8	237.5	17.375	17.5	17.5	17.5	17.47	28.125
175.1	184.9	17	17.125	17.125	17.125	17.09	27.75
124.3	134.0	16.5	16.5	16.625	16.5	16.53	26.875
90.4	100.1	15.75	15.875	15.875	16	15.88	26.25
70.5	80.2	15.125	15.25	15.375	15.125	15.22	25.625
52.7	62.4	14.25	14.25	14.375	14.375	14.31	24.375
30.2	39.9	12.625	12.75	12.875	12.625	12.72	22.375
30.6	40.3	12.375	12.375	12.375	12.5	12.41	21.875
10.5	20.2	11.875	12.125	12.375	12	12.09	21.625
11.8	21.5	10.5	10.625	10.75	10.5	10.59	19.75
w platen	8	8	8	8.125	7.75	7.97	16.625
w/o platen	0	3.625	4.75	4.375	3.75	4.13	15.375
w/o platen	0	2.5	3.5	3.125	2.75	2.97	19.375



APPENDIX E Specifications for Tire Shreds and Tire Bale Applications

**Beneficial Use Determination, Baled Tires in Road Construction,
New York State DEP, January 2003**

Texas DOT Preliminary Draft Specification for Tire Bale Embankments

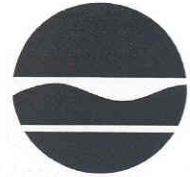
**Summary page for ASTM D 6270-98 Standard Practice for Use of Scrap Tires
in Civil Engineering Applications**

**New York State Department of Environmental Conservation
Division of Solid and Hazardous Materials, Region 9**

270 Michigan Avenue, Buffalo, New York, 14203-2999

Phone: (716) 851-7220 • FAX: (716) 851-7226

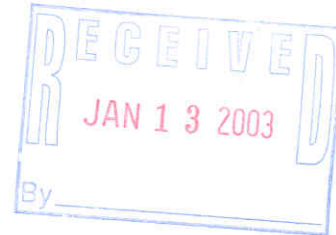
Website: www.dec.state.ny.us



Erin M. Crotty
Commissioner

January 9, 2003

Mr. Kenneth P. Smith
Deputy Director- Transportation
Chautauqua County Department of Public Facilities
454 North Work Street
Falconer, New York 14733



Dear Mr. Smith:

BUD #764-9-07

Use of Baled Tires in Road Construction

Department staff have reviewed the petition for a Beneficial Use Determination (BUD) submitted by Chautauqua County requesting the New York State Department of Environmental Conservation (Department) determine that waste tires, when baled and used as a substitute for lightweight aggregate (subbase) in road construction in marginal soils, constitutes a beneficial use. Chautauqua County stated that baled tires weigh one-fifth the weight of conventional materials used in road subbase construction. The County proposes to obtain waste tires from non-permitted waste tire piles and tire amnesty days, bale the tires at the Chautauqua County landfill, and use the tire bales pursuant to the County's Department of Public Facilities Division of Transportation planned road construction projects. The BUD petition submitted by Chautauqua County on September 18, 2002 is a case specific BUD petition for road construction using baled tires, however, specific future sites have not yet been identified.

On September 28, 1998, the Department issued a 6 NYCRR Research Development and Demonstration (RD&D) Permit (9-0699-00033/00001) to use approximately 2,000 tire bales for subgrade material on three unpaved road segments, each 1,000 feet in length. An EPA Waste Tire Stockpile Abatement/Demonstration grant was obtained by the County to partially fund the tire baler and clean-up of a waste tire stockpile used in the tire bales. The RD&D permit was renewed on November 24, 1999, and again on September 21, 2000, to include the use of baled tires under an asphalt road section (Kabob Road). The permit was amended on April 7, 2000 to include the collection of waste tires during amnesty days, and again renewed on July 24, 2002 to extend it through October 31, 2002.

Based on the information contained in the petition, and the evaluation of the performance during the RD&D permit, the Department is approving the Beneficial Use Determination requested by Chautauqua County, subject to the following conditions:

- 1) Tire baling shall be conducted at the Chautauqua County Landfill, located in the Town of Ellery. Baling shall be carried out in the same area where the tire bales are currently stored, on the west side of the border fence, east of the Landfill Transfer Station. Tire bales shall be stored at the landfill while awaiting placement.

- 2) No later than 30 days prior to commencement of construction of a new road section, the County must inform the Department, in writing, of the proposed work location, the length of road, the number of tires/tire bales involved, and dates of work. The County shall submit construction drawings and contract specifications, signed by a Professional Engineer licensed to practice in New York, which conform with condition No. 4 below.
- 3) Only NYSDEC 6 NYCRR Part 364 permitted Waste Tire Transporters may transport baled or unbaled tires.
- 4) The County shall use accepted engineering practices in the design and construction of the road. The placement of the waste tires as subbase shall be in accordance with applicable requirements of ASTM D6270-98 Standard Practice for Use of Scrap Tires in Civil Engineering Applications and in accordance with the recommendations of the New York State Department of Transportation (NYSDOT), which are contained in the June 17, 1998 letter from Wesley Moody to Jeffrey Schmitt, the Proposal to Bale Tires for Use in Subgrade Construction/ Research, Development & Demonstration (RD&D) Permit dated July 27, 1998, and the Application for Renewal to Permit dated October 29, 1999.
- 5) Signs shall be posted at the beginning and end of each road section (four signs for each section) which will clearly delineate the section of road containing the tire bales and advise motorists that the road surface may freeze prematurely. The County shall erect signage with language such as "The next 'x' feet of this road features baled whole tires as subgrade. Road surface may freeze faster than surrounding areas."
- 6) Chautauqua County, or the municipality where the road is located, shall routinely inspect and carry out maintenance and resurfacing operations to ensure that the tire bales remain in place, and do not become exposed.
- 7) An annual report must be submitted by March 1 of the following year to:

Mr. Mark Hans
Division of Solid & Hazardous Materials
NYSDEC
270 Michigan Avenue
Buffalo, NY 14203

Mr. Jeffrey Schmitt
Bureau of Waste Reduction & Recycling
NYSDEC
625 Broadway
Albany, NY 12233

The Department reserves the right to modify, suspend, or revoke this determination at any time should conditions warrant. Additionally, this determination does not exempt the operation from any other local, state, or federal requirements.

If you have any questions, please contact me at (716) 851-7220.

Sincerely,



Mark J. Hans, P.E.
Regional Solid Materials Engineer

cc: Mr. Jeffrey Schmitt, P.E.; Chief, Beneficial Use Section, Albany

SPECIAL SPECIFICATION

ITEM 1XXX

TIRE BALE EMBANKMENT

132.1. Description. Construct embankment courses composed of scrap tire bales and soil in accordance with the typical sections, lines and grades shown on the plans or as directed by the Engineer.

132.2. Material. Furnish materials of uniform quality that meet the requirements of the plans and specifications. Notify the Engineer of the proposed sources of materials to be used at least 30 days prior to production. Do not change any material source without written approval from the Engineer. When a source change is approved, the Engineer will verify that the specification requirements are met 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 the following type:

Type A. Furnish tire bales made of whole, used passenger or light to medium truck tires. Produce bales in a tire baler or equivalent as approved by the Engineer. Bales shall have a density not less than 35 lb/ft³. Provide a minimum of 5 galvanized steel or stainless steel straps or wires per bale. The bales shall not “explode” when all the straps are broken or cut. Bales shall be of uniform shape and size.

Furnish tire bales that only use scrap tires generated or stored within the State of Texas. Tire balers and baling sites shall be authorized to process scrap tires by the Texas Commission of Environmental Quality. Obtain approval of fire prevention and suppression plans by the Engineer and the local Fire Department 2 weeks prior to the commencement of baling and storing operations.

Load test representative tire bales with the bale fully supported on a test floor approved by the Engineer. Test each bale placed between two steel plates that completely cover the surface area of the top and bottom of the bale. The top steel plate shall be 1 inch thick. Distribute the load uniformly over the steel plate using a steel I-section beam as approved by the Engineer. Apply the load using a hydraulic ram with a load capacity of at least 400,000 lbs.

Conduct two types of strength tests, a creep test and a compressive strength test, for each tested tire bale. Conduct the creep test for 72 hours at a creep stress of 25 psi applied in the same direction as the loads are applied in the field. The maximum allowable creep strain shall not exceed 0.25. Conduct the compressive strength test until the tire bale fails or until an applied compressive stress of 100 psi is applied.

Furnish galvanized steel or stainless steel wires straps with a minimum break stress of 50 psi as applied on the tire bale surface. Corrosion of the straps shall meet the requirements of Item 423.2. Tire bale fills covered with geomembranes, which makes the tire fill impermeable to air and water, are not subject to the pH and resistivity requirements of Item 423.2.

132.3. Construction Methods.

(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. Complete all work prior to placing any embankment in accordance with Item 100, "Preparing Right of Way" on the areas over which the embankment is to be placed. Backfill stump holes or other small excavations in the limits of the embankments with suitable material and thoroughly tamp by approved methods before commencing embankment construction. Restore the surface of the ground, including disk-loosened ground or any surface roughened by small washes or otherwise, to approximately its original slope. Compact the ground surface by sprinkling and rolling where shown on the plans or required by the Engineer.

Notify the Engineer sufficiently in advance of opening any material source to allow performance of any required testing.

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

Do not place trees, stumps, roots, vegetation or other unsuitable materials in the embankment.

Unless otherwise shown on the plans, construct all layers approximately parallel to the finished grade of the roadbed.

Construct embankments 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, maintain it to its' finished section and grade until the project is accepted.

(2) Constructing Embankments.

(a) Tire Bale Embankments. Tire bale embankments shall be defined as those composed of scrap tire bales which comprise the core of the structure. The maximum height of the tire bale portion of the embankment shall not exceed 20 feet.

Construct a 12" granular base drainage layer at the bottom of the embankment before placing the tire bales as shown on the typical sections. Extend the granular base layer sufficiently to allow water to freely drain away from the embankment structure.

Construct the embankment such that infiltration of water and air is minimized. Place all tire bales with the restraining straps in the longitudinal direction of the roadway.

Place an 8 inch compacted soil layer between each tire bale layer. Use a soil with a PI less than 35 to provide a cushioning layer between successive layers of tire bales. Test all soil in contact with the tire bales Test Method Tex-408-A, Organic Color, with the test result not showing a color darker than standard. Furnish and place a geomembrane that meets Department specifications over the final layer of the tire bales to provide long-term durability to the embankment.

Provide an 18 inch minimum thick mineral soil layer free of organic matter on the side slopes. Place a 2-4 inch thick top layer of compost meeting the requirements of Item 161. Seed as directed under Item 164.

(3) Compaction Methods. Compaction of embankments shall be by "Ordinary Compaction".

Place each soil layer between the tire bales not to exceed twelve (12) inches of loose depth. Compact each layer 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. Continue compaction until there is no evidence of further compaction. Prior to and in conjunction with the rolling operation, bring each layer to the moisture content directed by the Engineer, and keep level 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.

When shown on the plans and when directed by the Engineer, proof roll in accordance with Item 216, "Rolling (Proof)". Correct soft spots as directed by the Engineer.

132.4. Tolerances. The tolerances shall be as follows:

(1) Grade Tolerances.

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

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

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

(2) Embankment will be measured by the each for the tire bales and by the cubic yard in

vehicles for the soil as delivered on the road.

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". This price shall be full compensation for furnishing tire bales; for soil; 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 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.


[Referenced Documents](#)
[Standards Search](#)
[Other Standards Products](#)

Document Summary

Copyright 2005 ASTM International. All rights reserved.

D6270-98(2004) Standard Practice for Use of Scrap Tires in Civil Engineering Applications

Developed by Subcommittee: [D34.06](#)
 See [Related Work](#) by this Subcommittee
 Adoptions:
 Book of Standards Volume: 11.04

CLICK TO VIEW
LICENSE AGREEMENT

1. Scope

1.1 This practice provides guidance for testing the physical properties and gives data assessment of the leachate generation potential of processed or whole scrap tires in conventional civil engineering materials, such as stone, gravel, soil, sand, or other materials. In addition, typical construction practices are outlined.

2. Referenced Documents

[C127](#) Test Method for Specific Gravity and Absorption of Coarse Aggregate
[D422](#) Test Method for Particle-Size Analysis of Soils
[D698](#) Test Method for Laboratory Compaction Characteristics of Soil Using Standard (12,400 ft-lbf/ft (600 kN-m/m))
[D1557](#) Test Method for Laboratory Compaction Characteristics of Soil Using Modified (56,000 ft-lbf/ft (2,700 kN-m/m))
[D2434](#) Test Method for Permeability of Granular Soils (Constant Head)
[D3080](#) Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions
[D4253](#) Test Methods for Maximum Index Density and Unit Weight of Soils Using a V Table
 T274 Standard Method of Test for Resilient Modulus of Subgrade Soils
 Method 1311 Toxicity Characteristics Leaching Procedure

Index Terms

construction practices; landfills; leachate; lightweight fill; retaining walls; roads; scrap tires
 83.160.01

APPENDIX F. References for Governmental Legislation and Scrap Tire Reuse Programs

**State Regulations on Scrap Tires, Colorado,
by Rubber Manufacturer's Association**

www Address for Scrap Tire Legislation Brief Sheets

State Scrap Tire Fees and Point of Collection

COLORADO

STATE REGULATIONS ON SCRAP TIRES

Scrap tire regulations for storage, disposal and processing facilities are found in Section 10 of state law, 6CCR 1007-2 Part A, the Colorado Regulations Pertaining to Solid Waste Disposal Sites & Facilities. These regulations:

- require all scrap tire recycling facilities to have a certificate of designation for a solid waste facilities.
- require operators of a scrap tire disposal facility to submit a plan for approval by the CO Dept. of Public Health and the Environment (CDPHE), which describes activities, equipment to be used, and inventory-tracking mechanism. As well, operators must submit annual reports on the amounts of scrap tires received at the facility, and the amounts recycled, disposal on-site, and shipped off-site.
- address maintenance of on-site roads, litter collection, fencing, signage, and on-site telephones.
- require facilities to have operating fire lanes and emergency readiness, and to report a fire or other emergency to CDPHE and the local health department, with details on causes, and corrective action.
- requires tire recycling and disposal facilities to have an attendant.

CRS 25-17-202 establishes the CO waste tire recycling development fee, set up Waste Tire Recycling Development Cash Fund, encourages source reduction and market development. After standard administrative costs, two-thirds of the monies go to the CO Dept. of Local Affairs (see next paragraph) and one-third goes to the CO Commission on Higher Education, which uses it for giving out grants from its Advanced Technology Fund on recycling and waste-related research.

CRS 24-32-114 allocates funds from the Waste Tire Recycling Development Cash Fund, to be administered by the CO Dept. of Local Affairs, on a proportional basis: 50% is for grants to jurisdictions to clean up illegal tire piles; 20% is for incentive grants to public entities purchasing products made from recycled Colorado-generated scrap tires; and 30 percent is partial reimbursement to end users and processors, up to \$50/T. Rules have been promulgated for the end user portion of the program under this statute. It authorizes the use of a consultant on scrap tire recycling and management matters at the CO Dept. of Local Affairs, in lieu of specialized staff knowledge. The use of inmate labor in waste tire cleanups is encouraged (and this is further supported in CRS 17-24-123).

More information on the Dept. of Local Affairs program is online at <http://www.dola.state.co.us/LGS/FA/wtf.htm>. More information on the CO Commission on Higher Education's Advanced Technology Fund is online at <http://www.state.co.us/cche/techno/waste.html>. Colorado statutes can be searched on a Lexis/Nexis public website at <http://198.187.128.12/colorado/lpext.dll?f=templates&fn=fs-main.htm&2.0>

MAJOR MARKETS

One cement kiln currently uses TDF as a supplemental fuel. A ground rubber producer markets patented soil amendment products to recreational and municipal uses. Several brokers supply ground rubber for use in roadway crack sealant products. A number of companies shred tires and sell them for uses such as alternate daily cover for landfills, soil reclamation projects, and other uses. Another company bales tires for uses such as construction material and for use on ranches. A pilot project by the CDPHE is expected to be complete in 2003, and approval is anticipated for the use of shredded tires in septic systems.

STATE CONTACTS

Anne Peters, CO Dept. of Local Affairs Waste Tire Program Consultant, Div. of Local Gov't, 303.494.4934 vox, 303.494.4880 fax, annep@indra.com email, 1313 Sherman St., Room 521, Denver, CO 80203

Glen Mallory, Department of Health, Hazardous Materials and Waste Management Division, 4210 East 11th Ave., Denver, Colorado 80220, telephone 303-692-3445, FAX 303-759-5355.

[About RMA](#) | [Newsroom](#) | [Become a Member](#) | [Member Directory](#) | [Contact Us](#) | [Sitemap](#)

[TIRE SAFETY](#) | [RMA RESOURCES](#) | [GENERAL PRODUCTS GROUP](#) | [SCRAP TIRES](#) | [PUBLIC](#)

SCRAP TIRES :: STATE ISSUES

[Scrap Tires and the Environment](#) | [Scrap Tire Markets](#) | [Conferences & Events](#) | [State Issues](#)

SCRAP TIRE LEGISLATION BRIEFING SHEETS

The following are files are downloadable PDF summaries of a state's legislation on scrap tire activities. Click on the below to see the details.

STATE	LAST UPDATED		
Alabama	2003	South Carolina	2003
Alaska	2003	South Dakota	2003
Arizona	2003	Tennessee	2003
Arkansas	2003	Texas	2003
California	2003	Utah	2003
Colorado	2003	Vermont	2003
Connecticut	2003	Virginia	2003
Delaware	2003	Washington	2003
Florida	2003	West Virginia	2003
Georgia	2003	Wisconsin	2003
Hawaii	2003	Wyoming	2003
Idaho	2003		
Illinois	2003		
Indiana	2003		
Iowa	2003		
Kansas	2003		
Kentucky	2003		
Louisiana	2000		
Maine	2003		
Maryland	2003		
Massachusetts	2003		
Michigan	2003		
Minnesota	2003		
Mississippi	2003		
Missouri	2003		
Montana	2003		
Nebraska	2003		
Nevada	2003		
New Hampshire	2003		
New Jersey	2003		
New Mexico	2003		
New York	2003		
North Carolina	2003		
North Dakota	2003		
Ohio	2003		
Oklahoma	2003		
Oregon	2003		
Pennsylvania	2003		
Rhode Island	2003		

State Scrap Tire Fees and Point of Collection:

Alabama	No Fee	TD pays county license fee
Alaska	No Fee	
Arizona	2% sales tax (Max \$2)	TD Collects
Arkansas	\$1.75 per tire	TD Collects
California	\$0.25 per tire	TD Collects
Colorado	\$1.00 per tire	TD Collects
Connecticut	No fee	
Delaware	No fee	
Florida	\$1.00 per tire	TD Collects
Georgia	\$1.00 per tire	TD Collects
Hawaii	\$ 1.00 per tire	Importer pays: New in 2000
Idaho	(\$1.00 per tire	TD Collected: Sunset 6-30-96)
Illinois	\$1.00 per tire	TD Collects
Indiana	\$0.25 per tire	TD Collects
Iowa	part of \$5 vehicle title fee	Collected by state
Kansas	\$0.50 per tire	TD Collects
Kentucky	\$1.00 per tire	TD Collects
Louisiana	\$2.00 per tire	TD Collects
Maine	\$1.00 per tire	TD Collects
Maryland	\$0.40 per tire	TD Collects: Amt. reduced in 2000
Massachusetts	No fee	
Michigan	\$0.50 per tire surcharge on vehicle title	State collects
Minnesota	\$4.00 on vehicle title transfers	State collects
Mississippi	\$1.00 per tire	TD Collects
Missouri	\$0.50 per tire	TD Collects
Montana	No fee	
Nebraska	\$1.00 per tire	TD Collects
Nevada	\$1.00 per tire	TD Collects
New Hampshire	No state fee; towns may levy fee	
New Jersey	No fee	
New Mexico	Add on to vehicle registration	State collects
New York	No fee	
North Carolina	2% sales tax	TD Collects
North Dakota	New vehicle sales fee	State collects
Ohio	\$0.50 per tire	Collected at wholesale level
Oklahoma	\$1.00 per pass/\$3.50 per truck	TD Collects
Oregon	(\$1.00 per tire	TD Collected: Sunset 10-1-92)
Pennsylvania	\$1.00 per tire	TD Collects: Spent on mass
transit		
Rhode Island	\$0.50 per tire	TD Collects
South Carolina	\$2.00 per tire	TD Collects

South Dakota	\$0.25 /tire/vehicle(\$1 max) registration fee	State collects
Tennessee	\$1.00 per tire	TD Collects
Texa	\$2.00 per tire	TD Collected: Sunset 12-31-97)
Utah	\$0.50 per tire	TD Collects
Vermont	No fee	
Virginia	\$0.50 per tire	TD Collects
Washington	(Retail fee	TD Collected: Sunset 1996)
West Virginia	\$5.00 per title	State collects: New in 2000
Wisconsin	(\$2.00 fee on vehicle titles	State collected: Sunset 6-30-96)
Wyoming	No fee	

Key: TD pays county license fee Tire dealer buys license from county to accept scrap tires
Importer pays: Whomever imports tires into Hawaii pays the fee.
TD Collects: Tire Dealer collects the fee at the tire retail sale
State collects: State collects the tire fee through the process by which
 the underlying fee is collected.
Wholesale level collects: Fee is collected from wholesaler on first sale in state.

Source: State Scrap Tire Programs A Quick Reference Guide: 199 Update, US EPA, Solid Waste and Emergency Response, EPA-530-B-99-002, August 1999

Additional information on post 1999 activity from published sources.

Summary:

States with active programs or fees: 35

- Tire dealer collects in 25
- State collects in 7
- Wholesale level collects in 1
- Tire dealer license in 1
- Importer pays in 1

Sunset programs: 5

- Tire dealer collected in 4
- State collected in 1

No fees: 10 states

Compiled By: Scrap Tire Management Council
1400 K Street, NW
Washington, D.C. 20005
202-682-4880
www.rma.org/tiresn.html

APPENDIX G. Fire Protection Issues and Guidelines for Scrap Tires

**The Colorado Department of Public Health and Environment, State Board of Health/Hazardous Materials and Waste Management Division
CCR 1007-2, Section 10, Scrap Tire Facilities.**

Title 14 California Code of Regulations Division 7 Integrated Waste Management Board (IWMB), Chapter 3, Article 5.5 titled Waste Tire Storage and Disposal Standards (Sections 17350 to 17356)

DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT

State Board of Health/Hazardous Materials and Waste Management Division

6 CCR 1007-2

PART 1 - REGULATIONS PERTAINING TO SOLID WASTE SITES AND FACILITIES

SECTION 1.0

ADMINISTRATIVE INFORMATION

Applicable to all existing or new solid waste facilities.

1.1 GENERAL INFORMATION

1.1.1 Authority These regulations are promulgated pursuant to the "Solid Wastes Disposal Sites and Facilities Act", Title 30, Article 20, Part 1, Colorado Revised Statutes (CRS), as amended. These regulations replace and supersede the "Solid Wastes Disposal Sites and Facilities Regulations", adopted February 16, 1972, and effective April 1, 1972.

1.1.2 Referenced materials This document may refer to documents produced by other agencies. All cited references are for that reference that is valid on the particular date of adoption of the pertinent section of these regulations and do not include later amendments or editions of the incorporated material. Copies of the referenced material may be reviewed during normal business hours at the Colorado Department of Public Health and Environment. Information on accessing the referenced documents may be obtained by contacting the:

Colorado Department of Public Health and Environment
Program Manager
Solid Waste Section
Hazardous Materials and Waste Management Division
4300 Cherry Creek Drive South
Denver, Colorado 80246-1530
Phone: (303) 692-3300

SECTION 10

SCRAP TIRE FACILITIES

10.1 GENERAL PROVISIONS AND APPLICABILITY

(A) All scrap tire facilities that are not regulated under the Recycling Section 8 of these regulations shall have a certificate of designation. On-site disposal shall comply with the applicable provisions of the Solid Waste regulations and shall occur at approved solid waste disposal facilities.

(B) This section 10.0 does not apply to facilities that recycle scrap tires in compliance with Section 8.0 of these Regulations.

10.2 STANDARDS FOR SCRAP TIRE DISPOSAL FACILITIES

10.2.1 (A) When applying for a certificate of designation, the operator of a scrap tire disposal facility shall submit a plan for approval by the Department and the local governing body. The plan shall describe, in detail, the nature of the activity, the types and capacities of equipment that will be used, all methods of processing and storage, the means to be used to track inventory on a volume or weight basis, and the proposed method and procedures for closure.

(B) Financial assurance for closure and post-closure care per Section 1.8 of these regulations is required of all scrap tire disposal facilities.

(C) Portions of Section 2 apply to scrap tire facilities as applicable to the nature of material being managed and the site-specific characteristics and that are not duplicated in this Section 10. Subsection 2.3 does not apply to scrap tire facilities.

10.2.2 An annual report shall be submitted by the facility to the Department and the local governing body by May 1 of each year. The report shall state the amounts of scrap

tires received at the facility, processed, disposed of on-site, and shipped off-site for the preceding calendar year.

- 10.2.3 The facility shall maintain all-weather access roads to those areas of active operation and as necessary to meet the fire control plan required by subsection 10.2.9 of these Regulations.
- 10.2.4 The facility shall collect litter in order to avoid a fire hazard or a nuisance and control the growth of vegetation to minimize potential fuel sources.
- 10.2.5 Adequate fencing, natural barriers or other security measures to preclude public entry shall extend around the entire perimeter of the facility and shall include a lockable gate or gates.
- 10.2.6 Prominent signs shall be posted in public view at the entrance to the facility with the name of the facility, the hours which the facility is open for public use, a listing of the wastes accepted at the facility, and a phone number for a 24-hour emergency contact. A copy of the Certificate of Designation resolution or the Certificate of Designation must be available for inspection at the site.
- 10.2.7 The operator shall maintain a working telephone at the facility.
- 10.2.8 (A) The operator of a scrap tire facility shall have a written vector control plan that shall be submitted to the Department and the local governing body.

(B) If pesticides are used in vector control efforts, they shall be used in accordance with the Pesticide Applicator's Act, C.R.S. § 35-10-101.
- 10.2.9 (A) The operator shall submit a fire control plan to the Department and the local governing body specifying the facility's fire lane locations and widths, the means that are assumed to be used to extinguish fires, and designation of a facility emergency coordinator.

This plan shall be in accordance with local fire codes and the plan shall be written by a qualified professional and submitted to and approved by the local fire control authority. A copy of the local fire control authority approval shall be forwarded to the Department.

(B) The minimum standards to be allowed for tire pile storage will be as follows:

(1) In no case shall storage piles of whole tires, tire bales, or tire shreds that are stored on open ground, as opposed to storage in open pits or cells, be larger than 50 feet in width and no higher than 15 feet above grade. An approved field measurement system must be employed to facilitate estimates of pile dimensions.

(2) A minimum of 40 feet shall be maintained between piles of whole, shredded, or baled tires to allow access for fire fighting equipment.

(3) A minimum distance of 50 feet of clear area is to be maintained from all property lines.

10.2.10 The facility shall immediately notify the local health department and the Colorado Department of Public Health and Environment in the event of a fire or other emergency. Within two weeks of this notification, the facility shall submit a report on the emergency to the Department and the local governing body. This report shall describe the origins of the emergency, the actions that have been taken, actions that are currently being taken or are planned, results or anticipated results of these actions, and an approximate date of resolution of the problems generated by the emergency.

10.2.11 During all stages of operation the facility shall have an attendant who is responsible for site activities.

Introduction
Search Regulations
Title 14 Home
Title 27 Home

Article 1

General
 Sections 17200 - 17201

Article 2

Purpose and Intent
 Sections 17202 - 17206

Article 3

Emergency Waiver of
 Standards
 Sections 17210 - 17210.9

Article 3.5

Temporary Waiver of Terms
 Sections 17211 - 17211.9

Article 4

Definitions
 Sections 17225 - 17225.74

Article 4.1

Waste Tire Program
 Definitions
 Sections 17225.710 -
 17225.820

Article 5

Solid Waste Storage and
 Removal Standards
 Sections 17301 - 17345

Article 5.4

Waste Tire Monofill
 Regulatory Requirements
 Sections 17346 - 17349

Article 5.5

Waste Tire Storage and
 Disposal Standards
 Sections 17350 - 17356

Article 5.6

Nonhazardous Petroleum
 Contaminated Soil
 Operations and Facilities
 Regulatory Requirements
 Sections 17360 - 17366

Article 5.7

Hazardous Waste Disposal
 Facilities Disposing
 Nonhazardous,
 Nonputrescible, Industrial
 Solid Waste Regulatory
 Requirements
 Sections 17367 - 17370.2

Article 5.8

Nonhazardous Ash
 Regulatory Tier
 Requirements
 Sections 17375 - 17379.1

Chapter 3. Minimum Standards for Solid Waste Handling and Disposal

Article 5. Solid Waste Storage and Removal Standards

Section 17301. Applicability of Standards.

The standards in this Article shall apply to all facilities, equipment, or vehicles used for storage, removal, transport, and other handling of solid wastes.

Section 17302. Conformance with plan.

After the effective date of the county solid waste management plan required by Section 66780 of the Government Code, solid waste storage and removal shall be in conformance with said plan.

Section 17311. General.

The owner, operator and/or occupant of any premise, business establishment, industry, or other property, vacant or occupied, shall be responsible for the safe and sanitary storage of all solid waste accumulated on the property.

Section 17312. Storage.

(H) In all cases in which garbage and rubbish are combined, the standards for garbage shall prevail. The property owner or occupant shall store solid waste on his premises or property or shall require it to be stored or handled in such a manner so as not to promote the propagation, harborage, or attraction of vectors, or the creation of nuisances.

Section 17313. Design Requirements.

The design of any new, substantially remodeled or expanded building or other facility shall provide for proper storage or handling which will accommodate the solid waste loading anticipated and which will allow for efficient and safe waste removal or collection. The design shall demonstrate to local land use and building permit issuing authorities that it includes the required provisions.

Section 17314. Operator Responsibility.

Where the collection operator furnishes storage containers, he is responsible for maintaining the containers in good condition (ordinary wear and tear excepted) unless they are furnished under other terms, conditions, or agreements. He shall plan with the property owner and/or occupant as to placement of storage containers to minimize traffic, Aesthetic and other problems both on the property and for the general public.

Section 17315. Garbage Containers.

Property owners and tenants shall deposit all garbage and putrescible matter or mixed garbage and rubbish in containers which are either non-absorbent, water-tight, vector-resistant, durable, easily cleanable, and designed for safe handling, or in paper or plastic bags having sufficient strength and water tightness and which are designed for the containment of refuse. Containers for garbage and rubbish should be of an adequate size and in sufficient numbers to contain without overflowing, all the refuse that a household or other establishment generates within the designated removal period. Containers when filled shall not exceed reasonable lifting weights for an average physically fit individual except where mechanical loading systems are used. Containers shall be maintained in a clean, sound condition free from putrescible residue.

Article 5.9

Construction and Demolition and Inert Debris Transfer/Processing Regulatory Requirements

Section 17380 - 17381.1
Section 17381.2 - 17383.5
Section 17383.6 - 17386

Article 5.95

Construction and Demolition Waste and Inert Debris Disposal Regulatory Requirements

Section 17387 - 17388.2
Section 17388.3 - 17390

Article 6.0

Transfer/Processing Operations and Facilities Regulatory Requirements

Sections 17400 - 17405.0

Article 6.1

Siting and Design

Sections 17406.1 - 17406.2

Article 6.2

Operating Standards

Sections 17407.1 - 17413

Article 6.3

Record Keeping Requirements

Section 17414 - 17414.1

Article 6.35

Additional Operating Requirements for Facilities Only

Sections 17415.1 - 17419.2

Article 8

Agricultural Solid Waste Management Standards

Section 17801 - 17824

Section 17316. Identification of Containers.

Containers of one cubic yard or more owned by the collection service operator shall be identified with the name and telephone number of the agent servicing the container.

Section 17317. Use of Container.

No person shall tamper with, modify, remove from, or deposit solid wastes in any container which has not been provided for his use, without the permission of the container owner.

Section 17331. Frequency of Refuse Removal.

(H) The owner or tenant of any premises, business establishment or industry shall be responsible for the satisfactory removal of all refuse accumulated by him on his property or his premises. To prevent propagation, harborage, or attraction of flies, rodents or other vectors and the creation of nuisances, refuse, except for inert materials, shall not be allowed to remain on the premises for more than seven days, except when:

- (a) disruptions due to strikes occur, or
- (b) severe weather conditions or "Acts of God" make collection impossible using normal collection equipment, or
- (c) official holidays interrupt the normal seven day collection cycle in which case collection may be postponed until the next working day. Where it is deemed necessary by the local health officer because of the propagation of vectors and for the protection of public health, more frequent removal of refuse shall be required.

Section 17332. Regulation of Operators.

Each person providing residential, commercial, or industrial solid waste collection services shall comply with all local government licenses, permits, or written approval requirements applicable to the city or county in which such services are provided. Such written approval shall be contingent upon the operator's demonstrated capability to comply with these standards and use of equipment which is safe and sanitary. Each enforcement agency of solid waste collection shall maintain a complete listing of all persons holding written approvals to provide solid waste collection services within its jurisdiction. The listing shall contain the name, office, address, telephone number and emergency telephone number if different of each such person, the number and types of vehicles employed by such person in providing such solid waste collection services, and the types of materials authorized for handling.

Section 17333. Operator Qualifications.

When a city, county or special district authorizes or designates a person or firm to provide solid waste collection services within the territory under its jurisdiction through contract, franchise, permit, or license the local government shall obtain proof that such person or firm has adequate financial resources and experience to properly conduct the operation authorized. The facts needed to establish proof shall include but not be limited to the following:

- (a) The filing of a performance bond or equivalent security with the local government in a reasonable amount, together with
- (b) Evidence submitted to the local government and to the enforcement agency that the person or firm has experience sufficient to meet the needs of the situation within the jurisdiction.

Section 17334. Ownership of Waste Materials.

Solid wastes subject to collection by a collection service operator shall become the property of the collection service operator subject to local ordinances or contract conditions after such time as the authorized collector takes possession of the wastes.

Section 17341. Equipment Construction.

(H) All equipment used for the collection and/or transportation of solid waste shall be durable, easily cleanable and designed for safe handling, and constructed to prevent loss of wastes from the equipment during collection or transportation. If such equipment is used to collect or transport garbage, other wet or liquid producing wastes, or wastes composed of fine particles, such equipment shall in all cases be non-absorbent and leak resistant. All equipment shall be maintained in good condition and cleaned in a frequency and in a manner so as to prevent the propagation or attraction of flies, rodents or other vectors and the creation of nuisances.

Section 17342. Equipment Safety.

(H) Vehicles and equipment used in the transport of garbage and rubbish shall be constructed and maintained in such a manner as to minimize the health and safety hazards to collection personnel and the public.

Section 17343. Equipment Parking.

A refuse collection service operator must designate an off-street location where all refuse collection vehicles will be parked when not in service, except in an emergency.

Section 17344. Identification of Operator.

Each vehicle used for the collection and transport of refuse shall be clearly marked with the name of the agency or firm operating the vehicle.

Section 17345. Inspection of Equipment.

(H) Equipment used for solid waste collection shall be made available for inspection as requested by the appropriate Enforcement Agency.

Article 5.5. Waste Tire Storage and Disposal Standards

Section 17350. Applicability.

(a) Any facility storing 500 or more waste tires outdoors must comply with the technical and operational standards in sections 17351 through 17355 of this Article.

(b) Any facility storing waste tires indoors must comply with the technical and operational standards in section 17356 of this Article.

(c) Waste tires that are disposed of by burying at a solid waste disposal facility are addressed in section 17355 of this Article.

(d) For purposes of determining the applicability of this Chapter, altered waste tires shall be counted as passenger tire equivalents (PTE).

Note:

Authority cited:

Section 40502, 42820, 42830 and 43020 of the Public Resources Code.

Reference:

Sections 42820, 42821, 42830, 42832 and 43020 of the Public Resources Code.

Section 17351. Fire Prevention Measures.

(a) Communication equipment shall be maintained at all facilities, if they are staffed by an attendant, to ensure that the site operator can contact local fire protection authorities in the event of fire.

(b) Adequate equipment to aid in the control of fires must be provided and maintained at the facility at all times. At a minimum the following items shall be maintained on site and in working order at all times:

- (1) One (1) dry chemical fire extinguisher;
- (2) One (1) two and one-half gallon water extinguisher;
- (3) One (1) pike pole or comparable pole at least 10 feet in length to separate burning from nonburning tires; and
- (4) One (1) round point and one (1) square point shovel.
- (5) One (1) dry chemical fire extinguisher with a minimum rating of 4A:40BC shall be carried on each piece of fuel-powered equipment used to handle waste tires;

(c) An adequate water supply shall be available for use by the local fire authority. The water supply shall be capable of delivering at least 1000 gallons per minute for a duration of at least three hours and at least 2000 gallons per minute for a duration of at least three hours if the sum of altered plus whole waste tires exceeds 10,000.

(d) All of the requirements of subsections (b) and (c) shall apply unless the local fire authority having jurisdiction over a particular facility determines that a different requirement is necessary or adequate to meet the intent of these regulations for fire control and the protection of life and property. This may include the availability of earth moving equipment or other approved means to control the tire fire. Any change in, or any new, local fire authority requirements that affect the requirements in this Article shall be reported to the Board by the operator within 30 days after their effective date. Any requirements approved by the local fire authority shall be subject to Board concurrence at the time of issuance or renewal of the permit.

Note:

Authority cited:

Sections 40502, 42820, 42830 and 43020 of the Public Resources Code.

Reference:

Sections 42820, 42821, 42830, 42832 and 43020 of the Public Resources Code.

Section 17352. Facility Access and Security.

(a) Signs--for facilities open to the public a sign shall be posted at the facility entrance stating the name of the operator, operating hours, and site rules.

(b) Attendant--An attendant shall be present when the facility is open for business if the facility receives tires from persons other than the operator of the facility.

(c) Access--An access road to the facility must be maintained passable for emergency equipment and vector control vehicles at all times. Unauthorized access must be strictly controlled.

Note:

Authority cited:

Sections 40502, 42820, 42830 and 43020 of the Public Resources Code.

Reference:

Sections 42820, 42821, 42830, 42832 and 43020 of the Public Resources Code.

Section 17353. Vector Control Measures.

(a) All waste tires shall be stored in a manner which prevents the breeding and harborage of mosquitoes, rodents, and other vectors by any of the following means:

(1) Cover with impermeable barriers other than soil to prevent entry or accumulation of precipitation; or

(2) Use of treatments or methods to prevent or eliminate vector breeding as necessary, provided the control program is approved as appropriate and effective by the local vector control authority, if such authority exists. If no local vector control authority exists, the local Environmental Health Department or other local agency with authority over vector control shall approve the vector control plan. Any control program approved by the local vector control authority shall be subject to Board concurrence at the time of issuance or renewal of the waste tire facility permit.

Note:

Authority cited:

Section 40502, 42820, 42830 and 43020 of the Public Resources Code.

Reference:

Section 42820, 42821, 42830, 42832 and 43020 of the Public Resources Code.

Section 17354. Storage of Waste Tires Outdoors.

(a) Except as provided in subsection (c) waste tires shall be restricted to individual piles, which include stacks and racks of tires that do not exceed 5,000 square feet of contiguous area. Any pile shall not exceed 50,000 cubic feet in volume or 10 feet in height. Piles shall not exceed 6 feet in height when within 20 feet of any property line or perimeter fencing. Waste tires shall not be located within 10 feet of any property line or perimeter fencing. The minimum distance between waste tire piles and between waste tire piles and structures that are located either on-site or off-site shall be as specified in Table I.

(b) Except as provided in subsection (c) waste tires shall be separated from vegetation and other potentially flammable materials by no less than 40 feet. Accessible fire lanes with a minimum width as specified in Table I shall be provided between tire storage units. Fire lanes shall be kept free of flammable or combustible material and vegetation. Access to fire lane(s) for emergency vehicles must be unobstructed at all times. Open flames, blow torches, or highly flammable materials, including but not limited to, tire inner tubes, are prohibited within 40 feet of a waste tire pile.

Table I Minimum Separation Distances (Ft.)			
Length of Exposed Face (Ft.)	Tire Storage Pile Height (Ft.)		
	6	8	10
25	50	56	62
50	66	75	84
100	84	100	116
150	99	117	135
200	111	130	149
250	118	140	162

(c) All of the requirements in subsections (a) and (b) shall apply to the storage of waste tires unless, for any particular requirement, the local fire authority having jurisdiction over a particular facility determines that a different requirement is necessary or adequate to meet the intent of these regulations for the prevention of fire and the protection of life and property. Any change in, or any new, local fire authority requirements that affect the requirements in this Article shall be reported to the Board by the operator within 30 days after their effective date. Any requirements approved by the local fire authority shall be subject to Board concurrence at the time of issuance or renewal of the permit.

(d) Surface water drainage shall be directed around and away from the waste tire storage area.

(e) Waste tires at existing waste tire facilities shall not be stored on surfaces with grades that will interfere with fire fighting equipment or personnel unless mitigation measures have been approved in writing by the local fire authority, or a fire safety engineer registered by the State of California. Measures established by a fire safety engineer shall be subject to approval by the local fire authority.

(f) New waste tire facilities shall not:

(1) Be sited in any area where they may be subjected to immersion in water during a 100-year storm unless the operator demonstrates to the Board that the facility will be designed and operated so as to prevent waste tires from migrating off site; or

(2) Be located on sites with grades or other physical features that will interfere with fire fighting equipment or personnel.

(g) Tires must be removed from rims immediately upon arrival at the facility.

(h) The site shall be designed and constructed to provide protection to bodies of water from runoff of pyrolytic oil resulting from a potential tire fire.

Note:

Authority cited:

Section 40502, 42820, 42830 and 43020 of the Public Resources Code.

Reference:

Section 42820, 42821, 42830, 42832 and 43020 of the Public Resources Code.

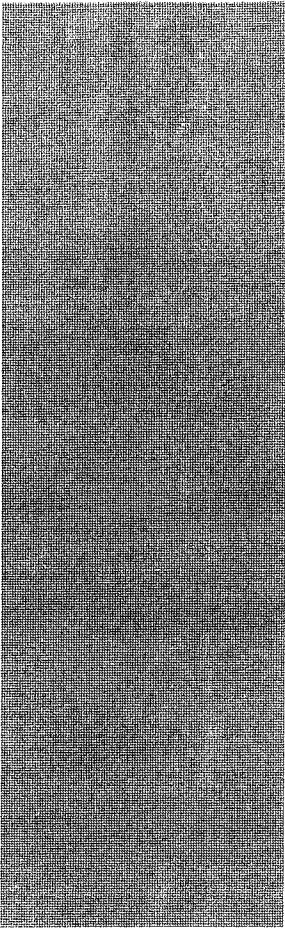
Section 17355. Disposal of Waste Tires at Solid Waste Facilities.

(a) Waste tires may not be landfilled in a solid waste disposal facility which is permitted pursuant to Chapter 3 of Part 4 of the Public Resources Code, commencing with section 44001, unless they are permanently reduced in volume prior to disposal by shredding, or other methods subject to the EA approval and Board approval.

(b) The requirement of subsection (a) shall not apply to: waste tires received which are commingled with municipal solid waste that arrive in loads, where the waste tires comprise less than one-half of one (0.5) percent by weight of the total load, or where the waste tires inadvertently arrive in homeowner delivered household loads of mixed waste and are not readily removable from the waste stream; or

(c) All waste tires stored at a solid waste facility shall meet the requirements of this Article.

Note:



Authority cited:

Section 40502, 42820, 42830 and 43020 of the *Public Resources Code*.

Reference:

Section 42820, 42821, 42830, 42832 and 43020 of the *Public Resources Code*.

Section 17356. Indoor Storage.

Waste tires stored indoors must be stored under conditions that meet or exceed those in "The Standard for Storage of Rubber Tires", National Fire Protection Association, NFPA 231D-1989 edition, published by the National Fire Protection Association, which is incorporated by reference. This requirement shall apply unless the local fire authority having jurisdiction over a particular facility determines that a different requirement is necessary or adequate to meet the intent of these regulations for fire control and the protection of life and property. Any change in, or any new, local fire authority requirements that affect the requirements in this Article shall be reported to the Board by the operator within 30 days after their effective date.

Note:

Authority cited:

Section 40502, 42820, 42830 and 43020 of the *Public Resources Code*.

Reference:

Section 42820, 42821, 42830, 42832 and 43020 of the *Public Resources Code*.

Last updated: January 13, 2004

Regulations <http://www.ciwmb.ca.gov/Regulations/>

Legal Office: dsturges@ciwmb.ca.gov (916) 341-6066

©1995, 2004 California Integrated Waste Management Board. All rights reserved.

APPENDIX H. Colorado DOT Costs for Embankment Materials and Related Items

The average unit material prices provided by CDOT in August 2004 for recent embankment projects are listed in the following table.

Table H.1 Average Colorado DOT unit prices for selected materials

CDOT Item	Volume (1,000 cb. yd)	2001		2002		2003		Total Projects	Ave. Cost (\$/cy)
		No. of Projects	Ave. Cost (\$/cy)	No. of Projects	Ave. Cost (\$/cy)	No. of Projects	Ave. Cost (\$/cy)		
703.08 (b) Class 2 Structure Backfill Material (Note 1) (Note 2)	<2.5	7	20.11	16	13.22	14	13.75	37	15.69
	2.5 to 5.0	5	14.34	5	9.81	5	10.45	15	11.53
	5.0 to 10.0	9	8.53	5	9.51	3	12.92	17	10.32
	10.0 to 50.0	9	7.32	11	6.22	11	7.69	31	7.08
	50.0 to 100.	7	4.77	2	5.97	5	6.21	14	5.65
	> 100.	4	5.06	4	3.36	3	3.29	11	3.90
<i>Subtotal or Average for 2,500 to 50,000 cy</i>		23	10.06	21	8.51	19	10.35	63	9.64
<i>Percent of Total</i>		56	NA	86	NA	46	NA	50.6	NA
Total or Average for 0 to >100,000 cy		41	10.02	43	8.02	41	9.05	125	9.03
703.08 (a) Class 1 Structure Backfill Material	NA								15.00 to 20.00
703.09 Filter Material (Note 3)	Class A	NA							30.37
	Class B	NA							44.53
	Class C	NA							21.84
Class A Separator geotextile, Table 712-8 (Note 4)	NA								Ave 2.00 (\$/sy)
Special Fill – Clean Sand	Estimated cost could range from \$15 to \$40 /cy, depends on availability, quantity, and transportation costs (Note 5)								Ave. 22.00
Notes: 1. Embankment replaced by tire bale fill. Total projects with volume < 50,000 cb. yd. = 80 % of typical projects 2. The data for 2003 includes 1 project of 1.858 million cy (at \$1.4 0 /cb. yd), plus annual volume of 1.103 million cb. yd. 3. Ave cost for 2001 to 2003. Use Class B for cost estimate for a base drain layer. See Table 7.3. 4. Use between tire bale fill and soil buffer layer. See Table 7.3. 5. Use in and around tire bales. See Table 7.3.									