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16. Abstract

This report summarizes the second phase of a three-phase project intended to evaluate the use of recycled materials in roadside safety devices. In the first phase of this project, information regarding recycled material manufacturers and their products was acquired through an extensive literature review and survey of research organizations, various state and federal transportation agencies, professional and trade societies, and manufacturers. The information received was categorized into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having possibility for use in such applications. Thus, in the second phase of this project, those products lacking the desired data were evaluated to make a conclusive decision regarding their suitability for implementation.

To date, 17 recycled material manufacturers having one or more products with potential application in the areas of interest have agreed to collaborate with Texas Transportation Institute on this study. Full-scale product specimens were obtained in order to account for size effects and the non-homogeneous nature of the materials. Received materials and products were sorted according to their potential uses for roadside safety applications. After the classification, the testing focused primarily on the applications of guardrail posts, guardrail offset blocks, and sign supports, which were all identified in Phase I as applications with high potential which lacked suitable recycled alternatives.

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LABORATORY TESTING OF RECYCLED MATERIALS IN ROADSIDE SAFETY DEVICES

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF TABLES

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

CHAPTER I - INTRODUCTION AND OBJECTIVE

STATEMENT OF PROBLEM

Rising materials costs have resulted in many products being recycled rather than buried in landfills. Several of these recycled products are in widespread use, or re-use, resulting in large quantities of inexpensive materials ready for use in new applications. In many instances products manufactured from recycled materials are becoming economically competitive with their original highway safety appurtenance counterparts.

Increased concerns for the environment also influenced the use of recycled materials. The depletion of natural resources at a faster rate than they can be replenished, the space limitations of existing landfills along with difficulties in developing new landfills, and the health hazards associated with the disposal of these materials were the primary reasons to increase interest in the use of recyclable materials. Roughly 4.6 billion tons of non-hazardous solid waste materials are produced annually in the US (Collins and Ciesielski, 1994). Domestic and industrial wastes constitute almost 600 million tons of this total. Wastes such as scrap tires, glass, and paper are receiving increased attention from state agencies, research organizations, and manufacturers. Although plastics constitute only 7 percent of the solid waste by weight, they compose approximately 12 to 20 percent of the total volume (Bloomquist, et al., 1993).

Systems or components of various roadside safety features are becoming candidates for use of recycled materials because they exhibit properties that are similar to those of products in use today. These recyclable components include, but are not limited to, guardrail posts and rails to post offset blocks, sign supports, energy absorbing elements in crash cushions, end treatments, and work zone traffic control devices, etc. The number of devices and cost figures for these devices installed and replaced annually within Texas and the nation become significant. Thus, the potential for effecting a measurable and positive impact on environmental problems in a cost-effective manner warrants further research.

Clearly, the movement toward increased utilization of recycled materials in highway safety is national in scope. However, the level of practice and knowledge of waste material recycling and use in roadside applications varies from state to state. Highway department personnel at all levels need to be aware of the various types of waste materials that can be recycled, applications for which they can be used, experiences of other agencies with these products, and their suitability based on technical, economic, and environmental considerations.

Further investigations are needed to determine basic properties of existing recycled materials and products, how those properties compare with the nationally recognized safety performances, and the practicality of application in terms of safety, availability, cost, durability, etc.

OBJECTIVE OF STUDY

In response to the increased interest in the use of recycled materials such as plastics, rubber, paper, glass, etc., the Texas Department of Transportation (TxDOT) sponsored research project 0-1458, entitled “Recycled Materials in Roadside Safety Devices.” The purpose of this project is to investigate and explore the use of recycled materials in roadside safety applications with the goal of product implementation. More specifically, the objectives of this project can be summarized as follows:

- identify existing or commercially available roadside safety products manufactured in part or whole from recycled materials and evaluate their suitability for implementation,
- determine fundamental properties of selected recycled materials and products considered candidates for use in roadside safety systems or components therein,
- evaluate the compliance of selected materials and products with nationally recognized safety performance standards,
- develop recommended performance standards and specifications for acceptable designs, and
- conceptualize new roadside safety system designs using recycled materials and products and recommend the most promising designs for further study.

Although mechanical properties for various recycled plastics blends and commingled products are known, the wide variations in chemical compositions, processing techniques, and admixtures preclude the development of a set of material specifications for a given application. Therefore, it becomes necessary to develop performance specifications for a given application based on a series of standard test procedures.

SCOPE AND RESEARCH APPROACH

This report summarizes the second phase of a three-phase project. In the first phase of this project, researchers acquired information regarding recycled material manufacturers and their products through an extensive literature review and survey of research organizations, various state and federal transportation agencies, professional and trade societies, and manufacturers. The search placed emphasis on those materials and products having possible applications in the roadside safety area. Upon identification, these manufacturers were contacted and asked to participate in this study. Researchers categorized the information received into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having potential for use in such applications.

Seventeen different manufacturers, having one or more products with potential application in the areas of interest, agreed to collaborate with Texas Transportation Institute (TTI) on this project. Full-scale specimens of products were obtained to account for size effects and the non-homogeneous nature of the materials. The received materials and products were sorted according to their potential uses for roadside safety applications. After the classification, the testing focused primarily on guardrail posts, guardrail offset blocks, and sign supports. These applications were all identified in Phase I as applications with high potential for the implementation of suitable recycled alternatives.

Phase II of this project involved a series of laboratory and dynamic tests of provided recycled products. Basic physical and mechanical properties were determined through static laboratory tests such as flexure, compression, creep, and density. Responses to environmental variables such as temperature, moisture, and freeze/thaw were investigated through exposure tests. The dynamic behavior of the materials was examined using pendulum tests. A unique test matrix was established for each application area such as sign supports and guardrail systems. Researchers tested current roadside safety products to provide baseline performances. The project determined basic utility of materials prior to dynamic tests to assure products would meet basic service requirements. For products displaying inadequate performance when compared with baseline products, modifications were made in collaboration with the manufacturer. As a result, several second and third generation products were submitted by the manufacturers for further testing. As these improved materials and products were received, they were tested and evaluated to quantify improvements in their properties and/or performance characteristics. After the final evaluation of the recycled materials and products, researchers recommended the most promising applications for Phase III of this project.

In addition to the evaluation of existing, commercially available recycled materials and products as described above, the project assessed other potential applications of recycled materials in roadside safety systems. Work under this task consisted of conceptualizing and/or identifying new innovative uses of recycled materials in the roadside safety area. Since development of these concepts requires considerable resources for engineering and testing, the effort conducted under this study was limited to the identification and formulation of conceptual designs and did not entail any actual construction or testing of prototypes.

The last phase of this project, Phase III, consists of full-scale crash testing of selected products to validate laboratory results and verify crashworthiness. Performance specifications will then be prepared for those applications for which suitable alternatives have been identified.

CHAPTER II - ROADSIDE SAFETY APPLICATIONS STUDIED

Roadside safety appurtenances and work-zone traffic control devices shield or delineate hazards along the roadside or in work zone areas of construction, rehabilitation, or maintenance. Although these devices are intended to protect motorists and maintenance crews, the devices themselves also constitute hazards and must be evaluated and demonstrated to be adequate. An understanding and evaluation of the existing test procedures and design requirements are essential long before the preparation of draft specifications for the recycled materials and products in highway safety applications.

To date, only a limited number of studies have been conducted to explore the potential uses of recycled materials for roadside safety applications. A few researchers (Bligh, et al. 1992, Strybos, 1993) show that the systems or components of various roadside safety features are candidates for use of recycled materials. This finding can likely be attributed to two factors: (1) lack of understanding of the engineering requirements (safety, strength, and durability) of the application under investigation, and (2) lack of understanding of material properties and behavior. It is clear, however, that further research is needed before wide application of these devices can be expected.

This chapter focuses on the conventional practice and the expected performance of some selected roadside safety applications such as guardrail posts, sign supports, offset blocks. Moreover, a series of test matrices is planned to determine the practicality of existing recycled materials and products for roadside safety applications as well as how they compare with the nationally recognized safety performance specifications.

A review of some design requirements and expected performances for some highway safety applications being considered for use with recycled materials are given below. As mentioned previously, a through understanding of these requirements is one of the two important factors in achieving a successful design; the other is a comprehensive knowledge of the material properties and behavior for the anticipated range of field conditions.

2.1 GUARDRAIL POSTS

2.1.1 Design Requirements and Expected Performance

Guardrail posts are being used in longitudinal traffic barriers on many roadways. The most widely used guardrail system in Texas and the nation is the strong post W-beam guardrail. Variations of this design have been successfully tested and are in use by many state transportation agencies. In Texas, two designs of the strong post W-beam guardrail systems are available for use. They differ by the type of guardrail post and offset block used. The most common system consists of a 178 mm (7 in) diameter round wood post embedded 965 mm (38 in) with a circular routed wood offset block. The other guardrail system uses a W150ς13.5 (W6ς9) steel post embedded 1118 mm (44 in) and routed wood offset block. It should be noted that the wood post design used by most other states consists of a 152 mm ς 203 mm (6 in ς 8 in) rectangular post and offset block with a standard embedment length of 1118 mm (44 in). For the basic test level, TL-3, *National Cooperative Highway Research Program* (*NCHRP) Report 350* recommends two tests for the evaluation of a guardrail system: test 3-10 and test 3-11. Test 3-10 involves an 820 kg (1806 lb) passenger vehicle impacting the barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this small car test is to evaluate occupant impact severity. Test 3-11 consists of a 2000 kg, 3/4 ton pickup truck impacting the barrier at 100 km/h (62 mi/h) and 25 degrees, and it is intended to evaluate the strength of the barrier in containing and safely redirecting the vehicle. Vehicle stability and post-impact trajectory are also evaluated for both tests.

Currently, there is no performance specification available for determining the structural adequacy of guardrail posts alone. The strength requirements are implied by the safety requirements outlined above. However, when designing a barrier system using guardrail posts, the general post behavior should be known beforehand. A strong-post guardrail system has limited deflections while a weak-post guardrail system has relatively large deflections. In a strong-post system, some of the impacting vehicle's kinetic energy is dissipated by rotation of the posts through the soil. Hence, guardrail posts employed in a strong-post system must have sufficient capacity to withstand impact loads while being rotated through the soil. Excessive deflections or premature post fracture may cause vehicular pocketing and or snagging that may result in rupture of the rail. Posts in the weak-post guardrail systems, on the other hand, are designed to yield or fracture readily in the path of the impacting vehicle. As a result, loads are carried through tension developed in the rail elements.

Due to the prohibitive cost of full-scale crash testing, developmental static and pendulum tests are often used to assess the suitability of guardrail posts prior to conducting compliance testing. The results of these tests can be compared to similar baseline tests conducted on conventional wood and steel guardrail posts. A post is said to be a candidate for use in a strong-post guardrail system if it possesses sufficient strength to yield or fail the soil when tested in an in-situ condition. If it fractures or yields at its base level before the failing of soil, it can be considered for use in a weak-post guardrail system.

2.1.2 Proposed Test Matrix

To identify the fundamental properties and characteristics of recycled guardrail posts gathered from existing and commercially available sources, laboratory and dynamic testing is proposed. In determining the test matrix, researchers considered availability of provided specimens and compatibility with laboratory equipment. Table 1 illustrates the proposed test matrix for the guardrail post specimens. The detailed information about the tests and laboratory procedures is given in Chapter IV.

Table 1. Proposed Test Matrix for Guardrail Posts.

Test Method	Purpose
Flexural Bending	Assessing the static mechanical properties, such as fracture strength, deformation, and energy absorption characteristics.
Hydrothermic Cycling	Determining strength deterioration or any other damage due to freeze/thaw cycles.
Impact Resistance	Evaluating the response characteristics to dynamic impact loads, fracture strengths, and energy absorption of the posts.
Density	Determining the densities of the posts.
Creep	Evaluating the time-dependent deflection characteristics of the posts.

2.2 SIGN SUPPORTS

2.2.1 Design Requirements and Expected Performance

There are many types of small sign supports that are widely used within the US. In Texas, there are five types of supports in use today: (1) steel U-post or flanged, (2) standard schedule 40 steel pipe, (3) fiberglass reinforced plastic, (4) thin-wall steel tubing, and (5) wood. The determination of number and type of supports is based on the sign area, loading conditions and user preference.

In terms of structural requirements, all sign supports are designed for loading conditions in accordance with American Association of State Highway Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals. The loading conditions for roadside sign supports include design wind loads, dead loads from sign blank and support, as well as ice loads when applicable.

Design wind loads used in the state of Texas are based on a 10-year mean recurrence interval. This indicates a design wind speed of 96 km/h (60 mph), which results in a reference wind pressure of 575 Pa (12 psf). The 10-year mean recurrence interval is used because of the relatively short life expectancy of sign structures. The minimum mounting height to the bottom of the sign blank is currently specified as 2.1 m (7 ft). Using this basic data along with the area of the sign blank, supports are designed to resist combined axial, bending, and shear stresses.

In addition to the structural requirements, sign supports are designed as breakaway structures to minimize damage and injuries during impact. This is achieved by providing a fracture or slip plane near ground level that allows the support to disengage from its foundation or ground stub when impacted. The standard pipe supports used by TxDOT incorporate one of two mechanisms: (1) a pipe collar coupling that permits fracture of the pipe through the threaded portion, or (2) a slip base that allows relative motion of the two base plates when the impact load exceeds the clamping force. Other supports, such as FRP, thin-walled steel tube, steel U-channel, and wood are designed to yield or fracture at or near the ground level.

The safety performance of breakaway supports is evaluated using both low speed and high speed impact tests. On both tests an 820 kg (1806 lb) passenger car is used. The low speed test is performed at 35 km/h (22 mi/h) and the objective is to evaluate the breakaway performance, fracture, or yielding mechanisms of the supports. The high speed tests conducted at 100 km/h (62 mi/h) assess vehicle stability and test article trajectory. Researchers evaluate occupant risk factors and occupant compartment intrusions for both tests.

Other test methods, such as bogie vehicle tests or gravitational pendulum tests are sometimes utilized to assess the safety performance of breakaway sign supports in lieu of full-scale crash testing. When a calibrated crushable nose assembly is used in conjunction with these alternate test procedures, the results are considered satisfactory for verifying proper activation of the breakaway mechanism and computing occupant risk factors such as occupant impact velocity and ridedown accelerations. However, lack of a compliant roof structure and windshield is the major shortcoming for these surrogate test vehicles. Hence, the evaluation of the integrity of the roof and the potential for occupant compartment intrusion becomes impossible. However, if occupant compartment intrusion is not a concern, surrogate test vehicles can be a cost-effective means of assessing dynamic impact performance.

Durability of small sign supports is generally not a major concern due to the relatively short life expectancy of these structures. To protect the thin-walled steel tubing, flange channel, or pipe supports against corrosive attacks and also prolong their life, they are generally galvanized or painted. Although the life expectancy may vary with the type of support used, a period of 15 to 20 years can be expected.

2.2.2 Proposed Test Matrix

Similar to the guardrail posts, a series of laboratory and dynamic tests need to be performed to identify the fundamental properties of the available recycled sign supports. Table 2 shows the proposed test matrix for the sign support specimens. In the process of determination of the test matrix, researchers considered specimen size limitations and laboratory equipment availability. The detailed information about the tests and laboratory procedures is given in Chapter IV.

Table 2. Proposed Test Matrix for Sign Supports.

Test Method	Purpose
Flexural Bending	Assessing the static mechanical properties, such as fracture strength, deformation, and energy absorption characteristics.
Hydrothermic Cycling	Determining strength deterioration or other damage due to freeze/thaw cycles.
Impact Resistance	Evaluating the response characteristics to dynamic impact loads, fracture strengths, and energy absorption of available supports.
Density	Determining the densities of the supports.
Creep	Determining the time-dependent deflection characteristics of the supports.
Warpage	Determining the possible warpage that may occur due to support's own weight and slenderness.

2.3 GUARDRAIL POST OFFSET BLOCKS

2.3.1 Conventional Practice and Expected Performance

In the steel-post guardrail system discussed in section 2.1, a W150ς13.5 (W6ς9) steel shape similar to that used for the post is used as a spacer block to offset the rail element from the face of the guardrail post. The purpose of the spacer block is to reduce vehicle interaction or snagging on the guardrail post during an impact. Excessive snagging can cause vehicle instability or impart excessive decelerations to the occupants. The W150ς13.5 (W6ς9) shape used in the steel-post guardrail system provides an offset distance of approximately 152 mm (6 in).

In contrast to the steel-post system, no offset block is used with the round wood post guardrail option. In the round wood post design, an offset block is unnecessary to achieve acceptable impact performance. Geometry of the round post reduces the severity of snagging. However, it should be noted that this behavior is based on an evaluation of the barrier under *NCHRP Report 230* (Michie, 1981), which is the predecessor of *NCHRP Report 350*. Since the test conditions contained in *NCHRP Report 350* are generally considered to be more demanding than those in *Report 230*, it is uncertain whether the omission of an offset block will continue to be acceptable in the standard guardrail system. The standard rectangular wood post guardrail system used across the country incorporates a 152 mm ς 203 mm (6 in ς 8 in) wood guardrail post offset block which provides an offset distance of approximately 203 mm (8 in).

Currently there are no performance specifications or laboratory test procedures recommended for the evaluation of guardrail offset blocks. The minimum strength requirements are dictated by the safety requirements. Because the offset block is a component of a guardrail system, it must be evaluated in conjunction with the rest of the system. Hence, the safety requirements for offset blocks are evaluated under the same test matrix and evaluation processes described in the previous section for guardrail posts.

In terms of durability, the conventional wood and steel offset blocks are treated or coated just as with the guardrail posts. Thus, a similar life expectancy of 15 to 20 years can be expected.

2.3.2 Proposed Test Matrix

To identify fundamental properties and characteristics of existing and commercially available recycled guardrail post offset blocks, a laboratory and dynamic test sequence is proposed. In the determination of the test matrix, researchers considered both the limitations in provided specimens and compatibility with available laboratory equipment. Table 3 gives the proposed test matrix for the guardrail post offset block specimens. The detailed information about the tests and laboratory procedures will be given in Chapter IV.

Table 3. Proposed Test Matrix for Guardrail Offset Blocks.

Test Method	Purpose
Compression Parallel to Longitudinal Axis	Determining the compressive properties, such as compressive strength, deformation, and energy absorption characteristics.
Hydrothermic Cycling	Determining strength deterioration or other damage due to freeze/thaw cycles.
Density	Determining the densities of the supports.

CHAPTER III - SOLICITATION OF RECYCLED MATERIALS

As mentioned previously, the first phase of this project involved gathering information regarding existing recycled materials and products. Researchers conducted an extensive literature review and survey of research organizations, government/state agencies, professional and trade societies, and manufacturers. The review placed emphasis on materials and products having possible applications in the roadside safety area. Upon identification, manufacturers were contacted and their involvement in this study was requested. The information received was categorized into two areas: (1) commercially available roadside safety products and traffic control devices ready for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having potential for use in such applications.

Seventeen recycled material manufacturers having one or more products with potential application in the areas of interest agreed to collaborate with TTI on this project. Table 4 lists received materials and their sizes. Full-scale product specimens were obtained to account for size effects and the non-homogeneous nature of the materials. The testing focused on the applications of guardrail posts, guardrail offset blocks, and sign supports. These applications were all identified in Phase I as areas with potential for success that lacked suitable recycled alternatives. Initial tests showed many of the products did not meet the necessary structural requirements for their respective applications. For those products displaying inadequate performances when compared to baseline performances, necessary modifications were made in collaboration with the manufacturers. In response, several manufacturers submitted second and third generation products. It should be noted that this procedure was primarily used for guardrail post applications where strength was the major concern for use in the strong-post guardrail system.

As these improved materials and products were received, they were tested and evaluated to quantify the extent of improvement in their properties and/or performance characteristics. The manufacturers were apprised of their products' performance after the evaluation process was completed.

Table 4. Summary of Received Recycled Materials and Sizes.

Specimen Code	Application	Product Description				
		Cross-Section	Material Type	Recycled Content %	Fabrication Process	Description
3.B.1	Guardrail Offset Block	7.2"x5.2"	HDPE	100%	Molded	Gray, small voids concentrated at center of cross section, voids comprise 0%-5% of cross-section, rough uniform surface texture
3.B.2	Guardrail Offset Block	7.2"x7.0"	HDPE	100%	Molded	Gray, small voids concentrated at center of cross section, voids comprise 0%-5% of cross-section, rough uniform surface texture
3.C.1	Guardrail Post	7.2"x5.0"	HDPE	100%	Molded	Black, small voids concentrated at center of cross section, voids comprise 0%-5% of cross-section, rough uniform surface texture
3.C.2	Guardrail Post	7.2"x7.0"	HDPE	100%	Molded	Black, small voids concentrated at center of cross section, voids comprise 0%-5% of cross-section, rough uniform surface texture
3.C.3	Guardrail Post	5.25"x7.25"	HDPE w/fiberglass	100%	Molded	Black, small voids concentrated at center of cross section, voids comprise 0%-5% of cross-section, rough uniform surface texture

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	**Applicatio n**	**Cross Section**	**Material Type**	**Recycled Content %**	**Fabrication Process**	**Description**
3.C.4	Guardrail Post	4.75"x7.25"	HMLI	100%	Molded	Black, small voids concentrated at center of cross section, voids comprise 0%-5% of cross section, rough uniform surface texture
3.C.5	Guardrail Post	5"x7.25"	HMLI w/fiberglass	100%	Molded	Black, small voids concentrated at center of cross-section, voids comprise 0%-5% of cross section, rough uniform surface texture
3.D.1	Sign Support	3.3"x3.3"	HDPE	100%	Molded	Black, small voids concentrated at center of cross-section, voids comprise 0%-5% of cross section, rough uniform surface texture
4.D.1	Sign Support	3.5"x3.5"	Commingled HDPE - LDPE (majority HDPE) / paper base	75% / 25%	Extruded into Mold	Maroon, little or no voids, rough uniform surface texture
4.D.2	Sign Support	4.5"x4.5"	Commingled HDPE - LDPE (majority HDPE) / paper base	75% / 25%	Extruded into Mold	Maroon to light brown, little or no voids, rough uniform surface texture
4.D.3	Sign Support	5.5"x5.5"	Commingled HDPE - LDPE (majority HDPE) / paper base	75% / 25%	Extruded into Mold	Black, little or no voids, rough uniform surface texture
5.D.1	Sign Support	3.5"x3.5"	Post-consumer, commingled plastics (#1 - #7)	100%	Extruded	Gray, w/ streaks of numerous colors, coarse due to surface irregularities

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	Application	Cross Section	Material Type	Recycled Content %	Fabrication Process	Description
5.D.2	Sign Support	3.5"x5.5"	Post-consumer, commingled plastics (#1 - #7)	100%	Extruded	Gray, w/ streaks of numerous colors, coarse due to surface irregularities
6.B.1	Guardrail Offset Block	7.7"x5.9"	Vinyl / Post-consumer LDPE film (shrink & stretch wrap)	50% / 50%	Continuously Extruded	Black, no voids, cross section has a velvet feel, rough uniform surface texture
6.C.1	Guardrail Post	6"x7.6"	Vinyl / Post-consumer LDPE film (shrink & stretch wrap)	50% / 50%	Continuously Extruded	Black, no voids, cross section has a velvet feel, rough uniform surface texture
7.D.1	Sign Support	3.4"x3.4"	HDPE	100%	Flow Molded	Colors range from tan to cream with some color variation throughout member, rough uniform surface texture, no visible voids
7.D.2	Sign Support	3.5"x5.4"	HDPE	100%	Flow Molded	Colors range from black to brown with some color variation throughout member, rough uniform surface texture, concentrated at center voids comprise 5% - 15% of cross section
7.C.1	Guardrail Post	5.4"x5.5"	HDPE	100%	Flow Molded	Black and tan with some color variation throughout member, rough uniform surface texture, concentrated at center voids comprise 0% - 10% of cross section

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	Applicatio n	Cross Section	Material Type	Recycled Content %	Fabrication Process	Description
8.D.1	Sign Support	3.6"x3.6"	HDPE	100%	Continuously Extruded	Variety of colors, one color per member, smooth uniform surface texture, no visible voids
11.D.1	Sign Support	4" OD	Post-consumer, commingled plastics (#1 - #7)	100%	Extruded into Mold	Gray/Maroon, coarse due to surface irregularities
14.D.1	Sign Support	4" OD	Concrete / Fiberglass			Gray and black thin fiberglass shell with concrete core, fiberglass shell has fibers longitudinally aligned with core, black cap on some of the ends
14.D.2	Sign Support	4.5" OD	Concrete / Fiberglass			Maroon thin fiberglass shell with concrete core, fiberglass shell has fibers transversely aligned with core, black cap on some of the ends
14.D.3	Sign Support	3" OD	Concrete / Fiberglass	Not Available		Black thin fiberglass shell with concrete core, fiberglass shell has fibers longitudinally aligned with core, black cap on some of the ends
14. C.1	Guardrail Post	6.75" OD	Concrete / Fiberglass	Not Available		Maroon thin fiberglass shell with concrete core, fiberglass shell has fibers transversely aligned with core, black cap on some of the ends

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	Application	Cross Section	Material Type	Recycled Content %	Fabrication Process	Description
14.C.2	Guardrail Post	10.75" OD	Concrete / Fiberglass	Not Available		Black thin fiberglass shell with concrete core, fiberglass shell has fibers transversely aligned with core
14.C.3	Guardrail Post	6.75" OD	Concrete / Fiberglass	Not Available		Maroon or white thin fiberglass shell with concrete core, fiberglass shell has fibers transversely aligned with core, black cap on some of the ends
15.D.1	Sign Support	3.5"x3.5"	HDPE	100%	Extruded	Light brown, no visual voids, rough uniform surface texture
17.B.1	Guardrail Offset Block	6.25"x8"	HDPE	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
17.C.2	Guardrail Post	6.25"x8"	HDPE	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
17.D.1	Sign Support	3.5"x3.5"	HDPE	100%	Extruded	Tan, no visual voids, rough uniform surface texture
17.D.2	Sign Support	3.5"x5.5"	HDPE	100%	Extruded	Tan, no visual voids, rough uniform surface texture

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	**Applicatio n**	**Cross Section**	**Material Type**	**Recycled Content %**	**Fabrication Process**	**Description**
20.C.1	Guardrail Post	5.4"x7.3"	HDPE, LDPE, PP	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.2	Guardrail Post	5.5"x7.5"	HDPE, LDPE, PP, w / 4 - 3/4" steel reinforcement	100%	Extruded	Black, 4 - 3/4" rebar located in corners approximately 1" from sides, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.3	Guardrail Post	7.3"x7.3"	HDPE, LDPE, PP	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.4	Guardrail Post	7.3"x7.3"	HDPE, LDPE, PP, w / 4 - 3/4" steel reinforcement	100%	Extruded	Black, 4 - 3/4" rebar located in corners approximately 1" from sides, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	**Applicatio n**	**Cross Section**	**Material Type**	**Recycled Content %**	**Fabrication Process**	**Description**
20.C.5	Guardrail Post	7.3"x7.3"	HDPE, LDPE, PP, w / 4 - 1.0" steel reinforcement	100%	Extruded	Black, 4 - 1.0" rebar located in corners approximately 1" from sides, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.6	Guardrail Post	10" OD	HDPE, LDPE, PP	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.7	Guardrail Post	5.25"x7"	HDPE, LDPE, PP	100%	Extruded	Gray, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.8	Guardrail Post	7"x7.37"	HDPE, LDPE, PP	100%	Extruded	Gray, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture
20.C.9	Guardrail Post	5.25"x7.25"	HDPE, LDPE, PP, w / 4 - 0.5" steel reinforcement	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	**Application**	**Cross Section**	**Material Type**	**Recycled Content %**	**Fabrication Process**	**Description**
20.C.10	Guardrail Post	5.25"x7.25"	HDPE, LDPE, PP	100%	Extruded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross-section, rough uniform surface texture
23.C.1	Guardrail Post	5.2"x5.2"	HDPE / LDPE / PS	Depends upon availability, typically 33.3% / 33.3% / 33.3%	Extruded into Mold	Black, tan, pink, green, orange, no visual voids, coarse due to surface irregularities
23.D.1	Sign Support	3.4"x3.4"	HDPE / LDPE / PS	Depends upon availability, typically 33.3% / 33.3% / 33.3%	Extruded into Mold	Black, tan, pink, green, orange, no visual voids, coarse due to surface irregularities
26.C.1	Guardrail Post	6"x8"	HDPE / screened waste fiberglass / misc. virgin material (foaming agent)	75% / 20% / 5%	Continuously Extruded	Gray, small voids concentrated at center of cross section, voids comprise 5%-20% of cross section, rough uniform surface texture
26.C.2	Guardrail Post	10"x10"	HDPE / screened waste fiberglass / misc. virgin material (foaming agent)	75% / 20% / 5%	Continuously Extruded	Gray, small voids concentrated at center of cross section, voids comprise 5%-40% of cross section, rough uniform surface texture
26.C.3	Guardrail Post	10" OD	HDPE / screened waste fiberglass / misc. virgin material (foaming agent)	75% / 20% / 5%	Continuously Extruded	Green, small voids concentrated at center of cross section, voids comprise 5%-40% of cross section, smooth uniform surface texture

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	**Applicatio n**	**Cross Section**	**Material Type**	**Recycled Content %**	**Fabrication Process**	**Description**
26.D.1	Sign Support	3.5"x3.5"	HDPE / screened waste fiberglass / misc. virgin material (foaming agent)	75% / 20% / 5%	Continuously Extruded	Gray, small voids concentrated at center of cross section, voids comprise 0%-5% of cross section, smooth uniform surface texture
26.D.2	Sign Support	5.5"x5.5"	HDPE / screened waste fiberglass / misc. virgin material (foaming agent)	75% / 20% / 5%	Continuously Extruded	Gray, small voids concentrated at center of cross section, voids comprise 0%-5% of cross section, smooth uniform surface texture
28.B.1	Guardrail Offset Block	6"x8"	Post-consumer, commingled plastics (can incorporate fiberglass)	100%	Molded	Black and gray, small voids concentrated at center of cross section, voids comprise 0%-5% of cross section smooth uniform surface texture, cannot tell if fiberglass is present
28.C.1	Guardrail Post	7.4"x5.2"	Post-consumer, commingled plastics (can incorporate fiberglass)	100%	Molded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture, cannot tell if fiberglass is present

Table 4. Summary of Received Recycled Materials and Sizes (Continued).

				Product Description		
Specimen Code	**Application**	**Cross Section**	**Material Type**	**Recycled Content %**	**Fabrication Process**	**Description**
28.D.1	Sign Support	3.5"x3.5"	Post-consumer, commingled plastics (can incorporate fiberglass)	100%	Molded	Black, small voids concentrated at center of cross section, voids comprise 0%-20% of cross section, rough uniform surface texture, cannot tell if fiberglass is present
30.C.1	Guardrail Post	6-7/8" OD	Not Available	Not Available	Not Available	Black, cross section composed of 1/4" rubber chunks, large cloth fibers, plastic fill, coarse surface due to irregularities
30.C.2	Guardrail Post	6"x8"	Not Available	Not Available	Not Available	Black, cross section composed of 1/4" rubber chunks, large cloth fibers, plastic fill, 1.5"x8"x10" boards bonded together with epoxy to form sample, coarse surface due to irregularities
31.C.1	Guardrail Post	6.5" - Dia.	HDPE tube w/ rubber chunks and polyurethane foam	Not Available	Not Available	Black HDPE tube w/ 1/4" walls, core made up w/a hardened foam material, smooth uniform surface texture
31.C.2	Guardrail Post	6.5" - Dia.	HDPE tube w/ rubber chunks and polyurethane foam	Not Available	Not Available	Black HDPE tube w/ 1/4" walls, core made up w/a hardened foam material, smooth uniform surface texture
32.D.1	Sign Support	3.7"x3.7"	HDPE, LDPE, PP	40% / 40% / 20%	Molded	Gray, no visible voids, rough uniform surface texture

CHAPTER IV - LABORATORY PROCEDURES

To assess whether a product satisfies a particular specification and provide uniform evaluation criteria among the available products, standard test procedures and methodologies must be established. In this phase of the project, a matrix of laboratory and field tests established evaluation criteria for recycled materials and products. The testing matrix was intended to:

- determine fundamental properties of available recycled materials and products,
- make comparisons among recycled plastics products,
- make comparisons between recycled plastics products and nationally recognized safety products with performance standards, and
- recommend the most promising products for the next phase of this project.

To achieve the objectives stated above, Phase II of this project involved a series of laboratory and dynamic tests to help researchers make decisions regarding the suitability for implementation of recycled materials and products. The materials were subjected to static laboratory tests, and in-situ static and dynamic load tests. Currently used nationally recognized roadside safety applications were also tested to provide some baseline performances for different applications. To overcome the inherent heterogeneity associated with their structure and accurately evaluate the behavior of the recycled materials and products, researchers used full-size specimens whenever possible.

From the strength standpoint, it appears possible to design products made with predominantly recycled materials to match the properties of wood. Consequently, recycled materials and products can conceivably be applied to various applications where wood is currently used. Moreover, it is well known that wood is extensively used in roadside safety applications such as guardrail posts, offset blocks, sign supports, and work zone traffic control devices (barricades). Clearly there is a need for further investigation of recycled materials for possible use in roadside safety applications.

Table 5 summarizes the proposed experiments as well as the tests that were conducted, and Table 6 shows a breakdown of the materials and sizes evaluated in each different test. Sixty different recycled products obtained from 17 different manufacturers were subjected to a number of physical, mechanical, and environmental tests. The experimental laboratory and fieldwork was performed jointly at Testing Machining and Repair Facilities (TMRF) at Texas A&M University (TAMU) main campus laboratories and Texas Transportation Institute at TAMU Riverside campus facilities between April 1996 and August 1997. The summary of the test methods used is given in the following sections.

4.1 FLEXURE

An understanding of the flexural behavior of a particular candidate material is necessary for performance evaluations of any engineering material. To determine the flexural strength of recycled plastic products, static bending tests were conducted for comparison with the flexural strength of similar conventional products. The flexural strength rating will be used in conjunction with other information to develop performance specifications for recycled material products.

Table 5. Summary of Phase II Experimental Plan.

No	Test Method	Procedure	Replicas	# Tested
1	Flexure	Cantilever and three-point bend tests with varying span to depth ratios were utilized. Tests performed at hot (40 EC), cold (0 EC) and room (23 EC) temperatures.	5	546
2	Compression Perpendicular to Longitudinal Axis	According to ASTM draft spec, full-size specimens with a shape of right prisms whose height was approximately twice the smaller dimension were tested. An adequate sized bearing plate was used.	5	120
3	Hydrothermic Cycling	According to ASTM draft spec, full-size specimens were subjected to a total of three cycles of water submersion, hydraulic stability, and freezing. Possible deteriorations were assessed with appropriate tests.	3	114
4	Impact Resistance	A gravitational pendulum facility with an 840 kg falling weight was utilized. To simulate flexible bumper effect, crushable nose made from honeycomb material was used.	3	72
5	Density	According to ASTM draft spec, full-size specimens were completely submerged in water using a sinker. The relative density was calculated based on the weight difference and known volume.	3	96
6	Creep	A cantilever setup was used. ASTM draft spec was followed. Specimens were subjected to a uniform stress level and deflections measured for a 10-day period.	3	69
7	Warpage	Specimens were embedded in a vertical orientation and subjected to environment conditions. Deflection measurements were made periodically.	3	66
8	Tensile	Coupons were tested to obtain modulus of elasticity of recycled materials. ASTM spec D637 was followed.	3	60

Table 6. Summary of Materials and Sizes Tested in Phase II.

Specimen Code	TEST METHOD													
	Flexure		Compression		Hydrothermic Cycling		Impact		Density		Creep		Warpage	
	No	Size[A] (mm x mm)	No	Size[B] (mm x mm)	No	Size[C] (mm x mm)	No	Size[D] (mm x mm)	No	Size[E] (mm x mm)	No	Size[F] (mm x mm)	No	Size[G] (mm x mm)
GUARDRAIL POSTS														
Wood	8[H]	184 – Dia.	N/A		N/A		3	184 - Dia.	3	184 - Dia.	3	184 - Dia.	N/A	
Wood	8[H]	152 x 203	N/A		N/A		3	152 x 203	N/A		3	152 x 203	N/A	
W6x9	8[H]	102 x 152	N/A		N/A		3	102 x 152	N/A		N/A		N/A	
3.C.1	5	127 x 183	N/A		N/A		N/A		N/A		N/A		N/A	
3.C.2	5	178 x 183	N/A		N/A		N/A		N/A		N/A		N/A	
3.C.3	8[H]	133 x 184	N/A		5	133 x 184	3	133 x 184	3	133 x 184	3	133 x 184	N/A	
3.C.4	8[H]	121 x 184	N/A		5	121 x 184	3	121 x 184	3	121 x 184	3	121 x 184	N/A	
3.C.5	5	127 x 184	N/A		N/A		N/A		N/A		N/A		N/A	
6.C.1	5	152 x 193	N/A		N/A		N/A		N/A		N/A		N/A	
14.C.1	5	175 - Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
14.C.3	8[H]	175 - Dia.	N/A		5	175 – Dia.	N/A		3	175 – Dia.	N/A		N/A	
17.C.1	5	159 x 203	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.1	5	137 x 185	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.2	5	140 x 191	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.3	5	185 x 185	N/A		N/A		N/A		N/A		N/A		N/A	

Table 6. Summary of Materials and Sizes Tested in Phase II (Continued).

Specimen Code	TEST METHOD													
	Flexure		Compression		Hydrothermic Cycling		Impact		Density		Creep		Warpage	
	No	Size[A] (mm x mm)	No	Size[B] (mm x mm)	No	Size[C] (mm x mm)	No	Size[D] (mm x mm)	No	Size[E] (mm x mm)	No	Size[F] (mm x mm)	No	Size[G] (mm x mm)
20.C.4	5	185 x 185	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.5	5	185 x 185	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.6	5	254 – Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.7	5	140 x 191	N/A		N/A		N/A		N/A		N/A		N/A	
20.C.8	8[H]	185 x 185	N/A		N/A		N/A		3	185 x 185	N/A		N/A	
20.C.9	8[H]	140 x 191	N/A		5	140 x 191	N/A		N/A		3	140 x 191	N/A	
20.C.10	5	140 x 191	N/A		N/A		N/A		N/A		N/A		N/A	
26.C.1	5	152 x 203	N/A		N/A		N/A		N/A		N/A		N/A	
26.C.2	5	254 x 254	N/A		N/A		N/A		N/A		N/A		N/A	
26.C.3	5	254 – Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
28.C.1	5	132 x 188	N/A		N/A		N/A		N/A		N/A		N/A	
28.C.2	5	155 x 206	N/A		N/A		N/A		N/A		N/A		N/A	
30.C.1	5	175 - Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
30.C.2	5	152 x 203	N/A		N/A		N/A		N/A		N/A		N/A	
31.C.1	5	175 – Dia.	N/A		N/A		N/A		N/A		N/A		N/A	

Table 6. Summary of Materials and Sizes Tested in Phase II (Continued).

Specimen Code	TEST METHOD													
	Flexure		Compression		Hydrothermic Cycling		Impact		Density		Creep		Warpage	
	No	Size[A] (mm x mm)	No	Size[B] (mm x mm)	No	Size[C] (mm x mm)	No	Size[D] (mm x mm)	No	Size[E] (mm x mm)	No	Size[F] (mm x mm)	No	Size[G] (mm x mm)
31.C.2	5	175 – Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
31.C.3	5	175 - Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
31.C.4	5	175 - Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
SIGN SUPPORTS														
Wood	8	89 x 89	N/A		5	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89
3.D.1	8	84 x 84	N/A		5	84 x 84	3	84 x 84	3	84 x 84	3	84 x 84	3	84 x 84
4.D.1	8	89 x 89	N/A		5	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89
4.D.2	8	114 x 114	N/A		5	114 x 114	3	114 x 114	3	114 x 114	N/A		3	114 x 114
4.D.3	8	140 x 140	N/A		5	140 x 140	3	140 x 140	3	140 x 140	N/A		3	140 x 140
5.D.1	8	89 x 89	N/A		5	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89
5.D.2	8	89 x 140	N/A		5	89 x 140	3	89 x 140	3	89 x 140	N/A		3	89 x 140
7.D.1	8	86 x 86	N/A		5	86 x 86	3	86 x 86	3	86 x 86	3	86 x 86	3	86 x 86
7.D.2	8	89 x 137	N/A		5	89 x 137	3	89 x 137	3	89 x 137	3	89 x 137	3	89 x 137
7.C.1	8	137 x 140	N/A		5	137 x 140	3	137 x 140	3	137 x 140	N/A		3	137 x 140
8.D.1	8	91 x 91	N/A		5	91 x 91	3	91 x 91	3	91 x 91	N/A		3	91 x 91
11.D.1	8	102 – Dia.	N/A		5	102 – Dia.	N/A		3	102 – Dia.	3	102 – Dia.	3	102 – Dia.

Table 6. Summary of Materials and Sizes Tested in Phase II (Continued).

Specimen Code	TEST METHOD													
	Flexure		Compression		Hydrothermic Cycling		Impact		Density		Creep		Warpage	
	No	Size[A] (mm x mm)	No	Size[B] (mm x mm)	No	Size[C] (mm x mm)	No	Size[D] (mm x mm)	No	Size[E] (mm x mm)	No	Size[F] (mm x mm)	No	Size[G] (mm x mm)
14.D.1	8	102 – Dia.	N/A		N/A		3	102 - Dia.	N/A		3	102 – Dia.	3	102 - Dia.
14.D.2	8	114 - Dia.	N/A		N/A		N/A		N/A		N/A		N/A	
14.D.3	8	76 - Dia.	N/A		5	76 – Dia.	3	76 – Dia.	N/A		3	76 - Dia.	3	76 – Dia.
15.D.1	8	89 x 89	N/A		5	89 x 89	N/A		3	89 x 89	3	89 x 89	3	89 x 89
17.D.1	8	89 x 89	N/A		5	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89	3	89 x 89
17.D.2	8	89 x 140	N/A		5	89 x 140	N/A		3	89 x 140	3	89 x 140	3	89 x 140
23.D.1	8	86 x 86	N/A		5	86 x 86	3	86 x 86	3	86 x 86	3	86 x 86	3	86 x 86
23.C.1	8	132 x 132	N/A		5	132 x 132	3	132 x 132	3	132 x 132	3	132 x 132	3	132 x 132
26.D.1	8	89 x 89	N/A		5	89 x 89	N/A		3	89 x 89	3	89 x 89	3	89 x 89
26.D.2	8	140 x 140	N/A		5	140 x 140	N/A		3	140 x 140	3	140 x 140	3	140 x 140
28.D.1	8	89 x 89	N/A		5	89 x 89	N/A		3	89 x 89	3	89 x 89	3	89 x 89
32.D.1	8	94 x 94	N/A		5	94 x 94	N/A		N/A		3	94 x 94	N/A	
GUARDRAIL OFFSET BLOCKS														
Wood	N/A		5	152 x 203	5	152 x 203	N/A		3	152 x 203	N/A		N/A	
W6x9	N/A		5	102 x 152	5	102 x 152	N/A		3	102 x 152	N/A		N/A	
3.B.1	N/A		5	127 x 178	5	127 x 178	N/A		3	127 x 178	N/A		N/A	

Table 6. Summary of Materials and Sizes Tested in Phase II (Continued).

Specimen Code	TEST METHOD													
	Flexure		Compression		Hydrothermic Cycling		Impact		Density		Creep		Warpage	
	No	Size[A] (mm x mm)	No	Size[B] (mm x mm)	No	Size[C] (mm x mm)	No	Size[D] (mm x mm)	No	Size[E] (mm x mm)	No	Size[F] (mm x mm)	No	Size[G] (mm x mm)
3.B.2	N/A		5	178 x 178	5	178 x 178	N/A		3	178 x 178	N/A		N/A	
6.B.1	N/A		5	152 x 203	5	152 x 203	N/A		3	152 x 203	N/A		N/A	
17.B.1	N/A		5	152 x 203	5	152 x 203	N/A		3	152 x 203	N/A		N/A	
26.B.1	N/A		5	152 x 203	5	152 x 203	N/A		3	152 x 203	N/A		N/A	
28.B.1	N/A		5	152 x 203	5	152 x 203	N/A		3	152 x 203	N/A		N/A	

A – Lengths of flexure specimens are 1219 mm (4 ft) for cantilever test and 1829 mm (6 ft) for 3-point bend test.
B – Lengths of the compression specimens are 356 mm (14 in).
C – Specimen lengths used for the hydrothermic cycling process changed based on the test requirements of the subsequent tests.
D – Lengths of the specimens are approximately 1829 mm (6 ft) for guardrail posts and 1675 mm (5.5 ft) for sign supports.
E – Lengths of the density specimens are 356 mm (14 in).
F – Lengths of creep test specimens are approximately 1800 mm (6 ft).
G – Exposed lengths of warpage test specimens are approximately 1800 mm (6 ft).
H – For the promising guardrails, three additional specimens were tested with three-point bend test.

4.1.1 Existing ASTM Standards

To establish an appropriate flexural testing procedure for recycled materials and products, American Society of Testing and Measurement (ASTM) standards related to the subject were investigated. Researchers found that for different types of materials such as wood, virgin plastics, and recycled plastics, ASTM standards differ slightly. Contents and applications of these different standards are summarized below.

The specification ASTM D198 covers the flexure test method for lumber in structural sizes. Employment of the four-point bend test is suggested to determine the flexural properties of structural beams made of solid or laminated wood. Beams of wood of uniform rectangular cross section having span to depth ratios of from 5:1 to 12:1 are suggested for obtaining accurate values.

The ASTM standard with a designation D790 covers the determination of flexural properties of unreinforced or reinforced virgin plastics. In this specification, both three- and four-point loading systems are suggested to determine the flexural properties of virgin plastics. For both tests, the support span will be 16 (tolerance +4 or !2) times the depth of the beam and a minimum of five specimens will be tested.

The last item is an ASTM draft specification covering the flexural properties of recycled plastics. In this draft specification, employment of a four-point bend test is suggested and a minimum of five specimens with rectangular or square cross section will be tested. Use of full-size specimens as manufactured along with a 16:1 span to depth ratio is recommended to obtain accurate results.

4.1.2 Laboratory Procedure

To determine the desired flexural properties of recycled materials and products, the project used two different types of test methods: (1) a cantilever fashion static bending test, and (2) a three-point bend test. Test setups for both tests are shown in Figures 1 and 2, respectively.

Since the sufficient flexural strength is a basic requirement for guardrail posts, the cantilever flexural test was used as a means to screen and select products for further testing and evaluation. Moreover, for the cantilever flexural test, the load was applied at what would be the center of guardrail or bolting height. As shown in Figure 1, this was achieved by applying a static load 533 mm (21 in) from the fixed end of the specimen. It should be mentioned this setup was successfully used in previous TTI projects to assess the failure modes of specimens (Bligh et al., 1995). Advantages of using this system are explained as follows: (1) the internal mechanisms that develop during the actual field performances of these applications are more accurately represented by a cantilever type loading, and (2) specimens as short as 1.22 m (4 ft) can be used.

To begin the cantilever test, a specimen was inserted into the clamping base and the fixture was tightened using eight high-grade A325 structural bolts and nuts. To prevent stress concentrations, the edge portion of the fixture, where the specimen bears during loading, was machined to have a 19 mm (0.75 in) radius. Specimens were loaded 533 mm (21 in) from the fixed end with a displacement controlled 20 ton capacity overhead crane (see Figure 1). The load rate was 0.4 in/sec. Load data was collected with a 178 kN (40 kips) pull-rod load cell. Data from the load cell and displacement from the crane were recorded using a microcomputer-based data acquisition system (see Figure 3). The tests were run until the specimens ruptured or 380 mm (15 in) of displacement was recorded. After completing the tests, researchers documented failure mechanisms of the specimens. The flexural results of the recycled plastics and products as well as the baseline products are given in Chapter V.

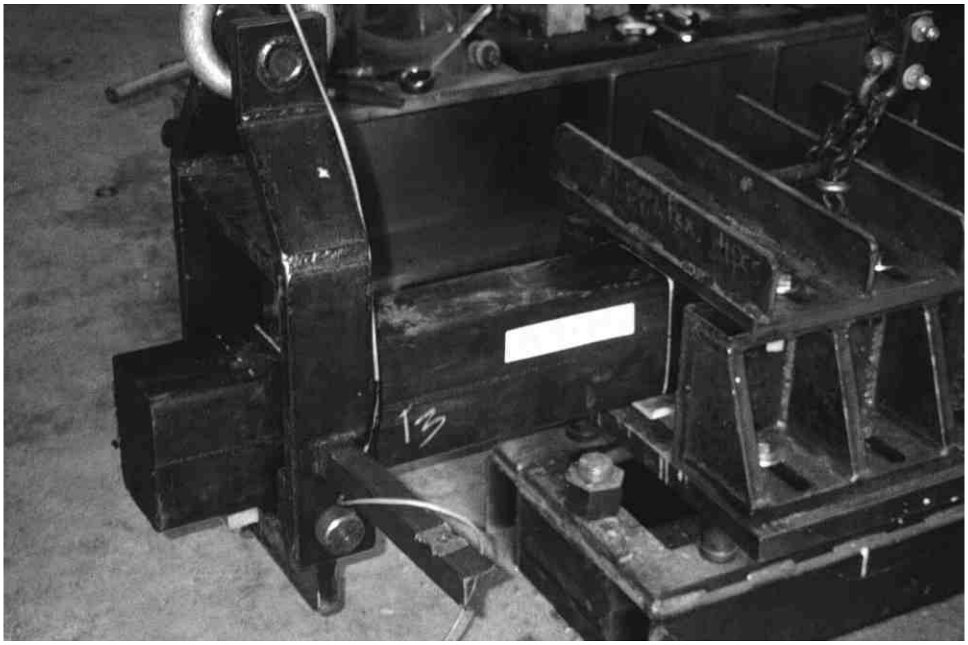

Figure 1. Cantilever Flexure Test Setup.

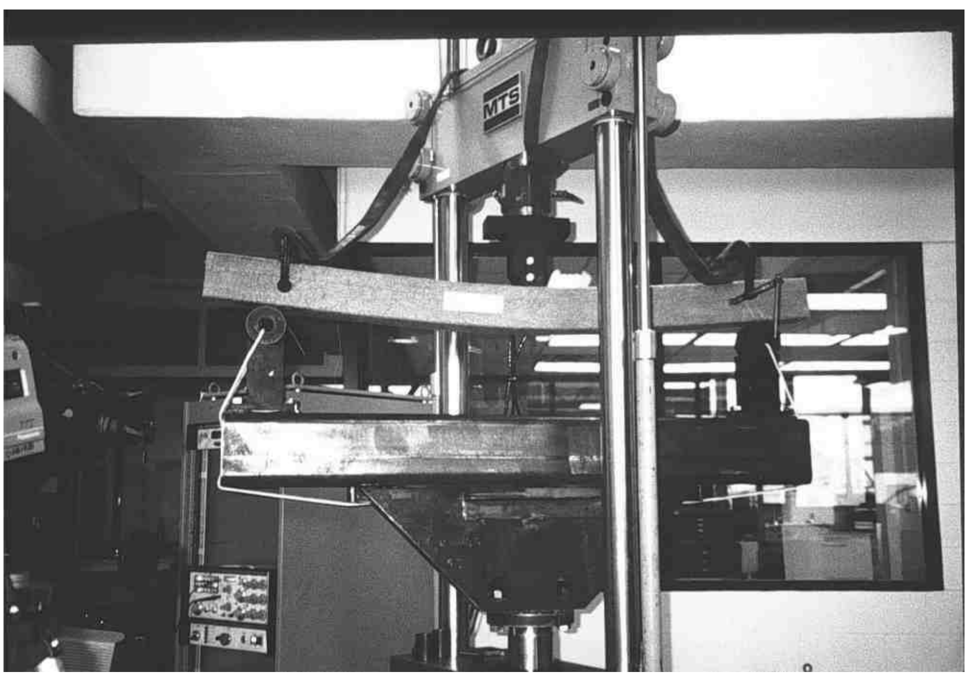

Figure 2. Three-Point Bend Flexure Test Setup.

Three-point tests were used to identify temperature effects on the flexural behavior of posts. However, the length of the available specimens did not meet the depth to span ratios suggested by the ASTM standards. The three-point bend test was employed for the flexural evaluation of specimens at the extreme hot and cold temperatures because smaller deflections were more easily accommodated in the controlled temperature boxes.

For the three-point bend tests, a 445 kN (100 kip) capacity Universal Testing Machine (UTM) was used. As shown in Figure 2, specimens were loaded at the mid-span by a loading nose whose diameter was 51 mm (2 in) and movement of the loading nose relative to the supports provided the deflected distance. The rate of the loading nose, R, was determined by the equation given in the ASTM draft specification as follows:

$$R = ZL^2 / 6d \qquad \textbf{Eq. (1)}$$

where R = rate of crosshead motion, mm (in)/min; L = support span, mm (in); d = depth of beam, mm (in); and Z = 0.01, rate of straining of the outer fiber, mm/mm.min.

The instrumentation and data acquisition system for the three-point bend test is shown in Figure 4. A span to depth ratio of approximately 10 was used due to limited lengths of specimens produced by the manufacturers. Specimens were loaded at the mid-span until the maximum stroke of 127 mm (5 in), provided by the UTM machine, was reached. Thus, only a few specimens reached their ultimate load carrying capacities. However, this test provided important information, such as relative stiffness and behavior change due to fluctuations in temperature.

To conduct the tests at hot (50 EC (120 EF)) and cold (0 EC (32 EF)) temperatures, researchers built an insulation box around the UTM machine. The specimens were stored in an insulated box until just before test time. To obtain accurate results, researchers kept specimens in temperature chambers several days until the temperature was uniform throughout the specimen. Thermocouples were used to determine conditioning and testing temperatures. During the tests, the temperature around the specimens was kept at 50 EC (120 EF) and 0 EC (32 EF) for the hot and cold tests, respectively. The temperature effects on the specimen responses as well as the trends that were observed due to the material compositions are discussed in Chapter V.

Figure 3. Cantilever Flexure Test Data Acquisition System.

Figure 4. Three-Point Bend Flexure Test Data Acquisition System.

To capture the true flexural performance of the recycled materials and products, tests used full-size, as-manufactured test specimens. whenever possible. Five representative samples were tested in the cantilever flexure test, while three representative samples were tested in the three-point bend test. Due to size variations in the received specimens, the sample lengths in the flexural tests varied between 1200 to 1800 mm (4 to 6 ft). The same flexural test methods were utilized for both guardrail post and sign support specimens to obtain uniform evaluation criteria. Flexure characteristics of offset blocks were not obtained in this study since flexure is not a concern for offset blocks.

4.2 COMPRESSION PERPENDICULAR TO LONGITUDINAL AXIS

The compression strength parallel to the long axis of plastic lumber is important for posts that will be installed by driving. However, none of the highway applications involve service loads acting parallel to the long axis of the member. In contrast, understanding of the behavior in compression perpendicular to the longitudinal axis is more critical for members that may experience direct impact loads due to errant vehicles. Hence, in this study only compression strength perpendicular to the longitudinal axis is considered.

4.2.1 Existing ASTM Standards

To establish a test procedure for compression perpendicular to longitudinal axis of recycled materials and products, pertinent ASTM standards were reviewed. The contents and applications of these standards are summarized below.

The specification ASTM D143 covers compression parallel to grain tests for small clear specimens of timber. The required dimensions of the test specimens are described as 51 mm H 51 mm H 203 mm (2 in H 2 in H 8 in). Adequate sized bearing plates should be used on the testing machine to obtain a uniform load distribution on the ends of the specimens.

Another specification with a designation D198 covers the determination of the compression properties of elements taken from structural members made of solid or laminated wood, or of composite constructions when such an element has a slenderness ratio less than 17. The method is intended for members of rectangular cross section, but the procedure also is applicable to irregular sections. The minimum dimensions of a test specimen is 51 mm H 51 mm (2 in H 2 in), and the minimum length of the specimen is greater than three times the larger cross section dimension or about 10 times the radius of gyration.

The last item is an ASTM draft specification on standard test methods for compressive properties of plastic lumber and shapes that are made predominantly with recycled plastics. In this draft specification, it is suggested that at least five specimens be tested and they be in a shape of a right cylinder or a prism with a height twice the smaller width or diameter.

4.2.2 Laboratory Procedure

To determine the compression behavior of available recycled plastics and products perpendicular to the longitudinal axis, compression tests were carried out in accordance with ASTM draft specifications. Compression tests were performed only on offset blocks since they were the only specimens that may be subjected to direct compressive impact loads during their service lives.

For compression tests, a 2224 kN (500 kips) capacity UTM machine was used. To obtain a uniform load distribution over the test specimens, researchers equipped the head of machine with an adequate load plate. As shown in Figure 5, the load was applied perpendicular to the longitudinal axis of the specimens using a 406 mm (16 in) long bearing plate. Full-size specimens with a shape of right prisms with a height approximately twice the smaller dimension were used. Width and depth measurement of specimens varied; however, the height of all specimens was 355 mm (14 in).

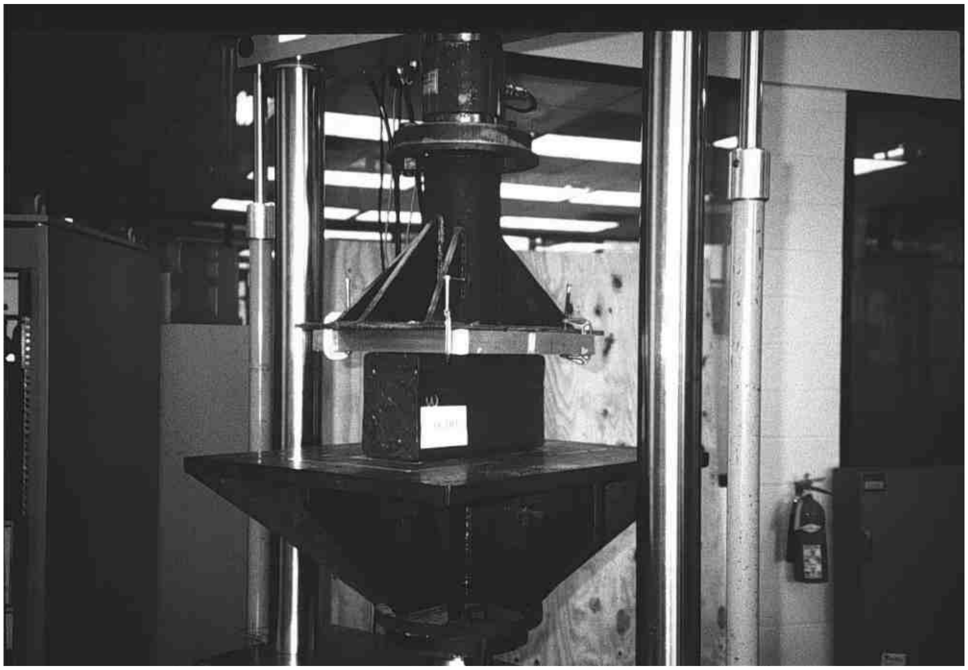

Figure 5. Compression Test Setup.

Compression tests were carried out at temperatures 0, 23, and 50 EC (32, 74, and 120 EF) to assess the temperature effects on test specimens. As suggested by the ASTM specifications, five representative samples of all products were tested at room temperature. However, due to a shortage in the number of specimens, only three representative samples were tested at the high and low temperatures.

To perform the compression tests at extreme temperatures, researchers built an insulation box around the mobile head of the UTM machine. To achieve complete thermal isolation, additional care was taken also at the base of the UTM machine. An entire picture of the isolation box is shown in Figure 6. Specimens were pre-heated or cooled in temperature chambers before testing.

For the test performed at 50 EC (120 EF), special heat belts were installed inside the isolation box to keep the temperature within that temperature. For cooling, Freon gas was used to maintain the temperature at 0 EC (32 EF). The temperature in the box was monitored by thermocouples. The tests were not conducted until stable desired temperatures were recorded in the box.

Figure 5 shows the test setup for the tests conducted at room temperature. Load-deformation data was gathered using a microcomputer-based data acquisition system as shown in Figure 7. The strain rate used for compression tests was 0.03 mm/mm (in/in) per minute and it was based on the ASTM draft specifications.

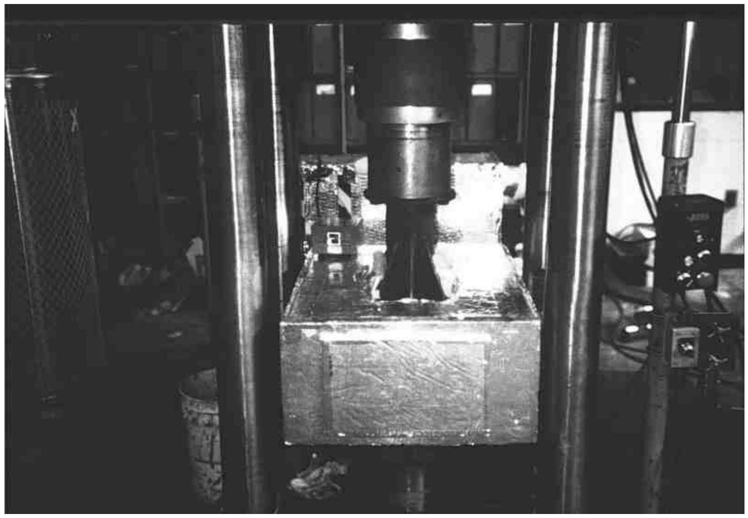

Figure 6. Compression Test Insulation Box Setup.

Figure 7. Compression Tests Data Acquisition System.

4.3 HYDROTHERMIC CYCLING

Materials used in highway applications are exposed to outdoor environments and some are affected by the seasonal temperature and moisture fluctuations. Products with low densities and/or voids can absorb water from the outside environment. Once the temperature drops below freezing, the water trapped in the material freezes and the associated expansion can cause damage. As a result, product performance may be degraded. Therefore, determining the susceptibility of recycled materials to hydrothermic cycling damage is necessary. Hydrothermic cycle testing should indicate whether cracking, spalling, and strength deterioration will occur as a result of temperature and moisture changes in recycled materials.

4.3.1 Existing ASTM Standards

To establish an appropriate hydrothermic cycling process for recycled materials and products, researchers investigated ASTM standards related to the topic. An ASTM draft specification that addresses the procedures for hydrothermic cycling for recycled plastic materials was located.

The hydrothermic cycling process is described as pre-conditioning and consists of three total cycles of water submersion, hydraulic stability, and freezing. Test specimens are suggested to be full size as-manufactured. The specimen and number length and the methods of specimen preparation are to be determined by the subsequent test requirements.

4.3.2 Laboratory Procedure

Researchers performed the hydrothermic cycling process to quantify the reduction in strength due to freeze/thaw cycles that a material could experience during its lifetime. Tests were conducted on all sign supports, guardrail offset blocks, and only qualified guardrail posts.

As outlined in the draft specification, after preparation of the specimens, each sample was weighed and totally submerged for a period of 24 hours using weights as shown in Figure 8. At the end of a 24 hour period, each sample was dried on the outside surface and reweighed within 5 minutes of removal from water. Samples that exceeded a 1 percent weight gain as compared to the unsoaked samples were resoaked until the change in the weight was less than 1 percent per 24 hour period. Such samples were considered to have reached "hydraulic stability." Samples were then frozen to !40 EC (!40 EF) for 24 hours and then returned to room temperature. This process comprised one hydrothermic cycle and was repeated three times, that is, all samples were subjected to a total of three cycles of water submersion, hydraulic stability, and freezing.

After the completion of these pre-conditioning steps, specimens were subjected to a series of mechanical tests at room temperature. Guardrail post and sign supports were subjected to flexure as outlined in section 4.1.2, and offset blocks were subjected to compression tests as described in section 4.2.2. The results of the mechanical tests and discussion about these findings are given in Chapter V.

Figure 8. Hydrothermic Cycling Water Process Immersion Setup.

4.4 IMPACT

Impact performance is an important parameter for a number of highway applications. In particular, sign supports must break away under impact, while guardrail posts in strong-post guardrail systems must have sufficient strength and impact resistance to safely redirect a vehicle. The results obtained from impact tests can be used to determine the possible failure mechanisms and deceleration characteristics due to the product deflections.

Impact tests were performed to assess the breakaway performance of sign supports manufactured from recycled materials. Breakaway behavior is the governing factor ensuring satisfactory safety performance for sign supports.

4.4.1 Existing ASTM Standards

It is suggested by ASTM standard D256 that impact resistance of plastics is determined by pendulum tests on notched specimens. Notches are inserted to reduce the strength and assure specimen failure. Two different methods are described to determine the average impact resistance, a cantilever beam (izod-type) test and a simply supported beam (charpy-type) test.

4.4.2 Laboratory Procedure

Impact tests were conducted at TTI's outdoor gravitational pendulum facility at the Texas A&M Riverside campus. This pendulum facility has been successfully used in numerous research projects involving highway safety appurtenances. It was designed to simulate low-speed 40 km/h (25 mi/h) vehicle impacts on roadside appurtenances. The pendulum, as shown in Figure 9, is an 840 kg (1852 lb) falling weight that imparts a known kinetic energy to a test article for evaluation of deceleration and failure characteristics. A crushable nose made of honeycomb is used to simulate the crush characteristics of a small passenger car. The specimens were embedded in standard soil as specified in *NCHRP Report 350* for testing of highway safety appurtenances. Two uniaxial accelerometers mounted on the rear of the pendulum measured acceleration levels. Electronic signals from the accelerometers are telemetered to a ground station for recording and display on a real-time strip chart. Analog signals are then digitized for import into a spreadsheet for analysis.

Impact tests were conducted on all sign supports and on the qualified guardrail posts. Full-size members were used. Three representative samples were tested for each product. All tests were conducted outdoors.

Figure 9. Pendulum Equipment Used for Impact Test.

Two different embedment lengths were used in the guardrail post tests. The total length of specimens was approximately 1.8 m (72 in) with the embedment lengths of 914 mm (36 in) and 1118 mm (44 in) simulating the two different cases. The point of impact was 0.55 m (21.8 in) above ground level to simulate the small vehicle impact.

The total length for the sign supports was approximately 1600 mm (65 in). The point of impact was again 550 mm (21.8 in) above ground level. Specimens were inserted in a rigid ground sleeve. This method was utilized to: a) represent concrete embedment in the field, b) insure breakaway performance for evaluation purposes, and c) expedite the testing procedure.

Installation of the guardrail posts was accomplished by drilling a 0.61 m (2 ft) diameter hole and centering the specimen in the hole. Soil was then backfilled and compacted in 150 mm (6 in) lifts. As mentioned above, sign supports were inserted in a rigid foundation tube. Wedges were then driven between the posts and foundation tube to prevent slippage during the test.

When the preparation was completed, the pendulum was raised 4.6 m (15 ft) and released. The discussion of results is given in Chapter V.

4.5 DENSITY

The density of a material is defined as the mass or weight per unit volume. It is sometimes useful to compare competing products based on relative weights, strengths, and costs. Recycled product uniformity can also be monitored by density measurement. As density increases, with given product dimensions, weight increases. As weight increases, associated costs such as shipping and labor costs will also increase. Therefore, it is desirable to have lighter recycled products provided the strength and serviceability requirements are met.

4.5.1 Existing ASTM Standards

ASTM standard D792-91 states the procedure for finding relative densities of solid plastics, in forms such as sheets and rods. ASTM standard D2395 addresses several ways of determining the relative density for wood and wood-base materials. The method for finding density is determined by the required accuracy, size, shape, and moisture content of the specimen. Among the methods suggested, water immersion and mercury immersion techniques are encouraged.

An ASTM draft specification describing a standard test method for density of plastic lumber and shapes, made from predominantly recycled plastics, was also identified. It suggests density be determined by immersion of the entire item or a representative cross section into air-free water. Testing five specimens per sample is recommended. The method involved the following steps. The mass of the specimens is recorded to the nearest 1 mg as “a.” Specimens are then immersed in gas-free distilled water; the specimen’s apparent weight upon immersion is determined as “b.” If the sinkers are used for immersion, the weight of the wire, cage, and sinker, called “w,” will be included when determining “b.” Thus, the apparent overall density is calculated by dividing (a + w !b) into “a.”

4.5.2 Laboratory Procedure

The ASTM draft specification was followed to determine the densities of the recycled materials and products. Density tests were conducted on full-size specimens to account for heterogeneity of recycled materials. Three representative samples were tested for all products. The lengths of the specimens were selected to be 355 mm (14 in), the original length of the offset blocks. Hence, only the sign support and guardrail post specimens were cut. Members having porous sections were sealed with a tape as suggested by the draft specification to prevent water penetration into the specimens.

To start the procedure, all samples were first weighed dry and the weights were recorded as “a.” A 0.76 m (2.5 ft) deep, 0.3 m ς 0.9 m (12 in ς 36 in) wide container filled with gas-free distilled water at 23 EC (73 EF) was used to immerse the specimens (see Figure 10). A sinker was used to completely immerse plastics that are lighter than water. The sinker consisted of a heavy base plate and a fine wire to hold the specimens to the sinker (see Figure 10). A hydraulic hoist, as shown in Figure 10, lowered the specimens into the water and a small load cell captured the weights. These values were recorded as the “b” values. It should be noted that the weight of the sinker, “w,” was also included in “b.” The overall density of specimens was calculated by dividing “a” by (a + w ! b).

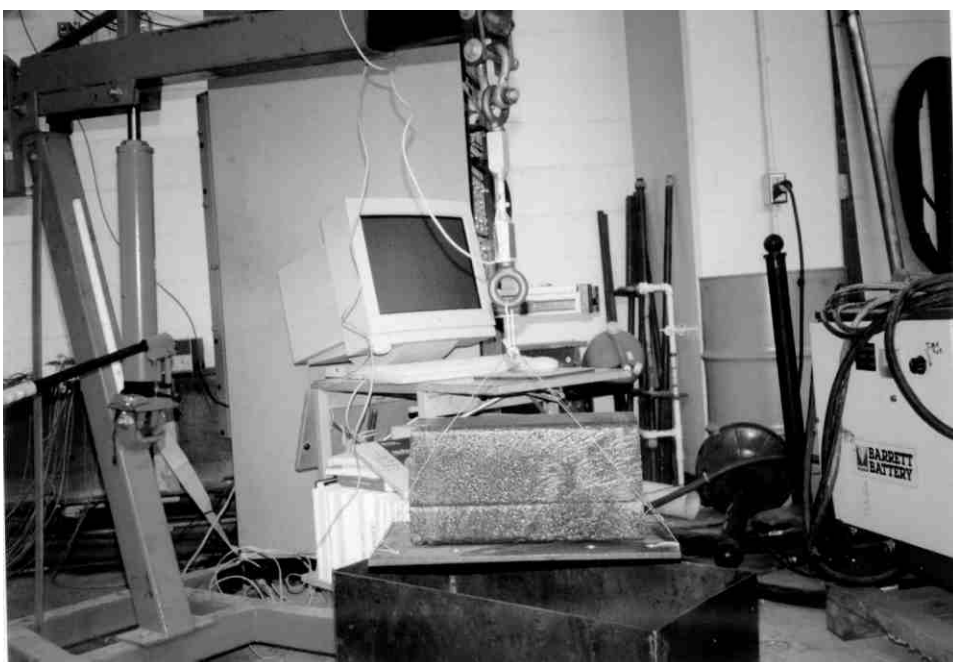

Figure 10. Relative Density Test Setup.

4.6 CREEP

Plastics are much more prone to creep than conventional wood and steel materials. Creep is defined as a progressive deformation of a material while subjected to a constant stress over time (Ontario, 1993b). Research shows that thermoplastics are particularly susceptible to creep, with greater creep occurring at higher temperatures. Performance problems may be encountered with sign supports, from a utility standpoint, as the long slender columns are subjected to significant stationary service loads. Thus, it is necessary to understand the creep behavior of recycled materials and products under long term loads to predict dimensional or geometric changes that may occur.

4.6.1 Existing ASTM Standards

Researchers identified two separate ASTM standards that address creep susceptibility of plastics. Both discuss flexural creep and pertinent testing methods.

The first method, ASTM D2990, determines flexural creep of virgin plastics under specified environmental conditions. The suggested test apparatus is similar to conventional flexure test apparatus. The specimen is supported at both ends on a rigid test rack. Recommended span to thickness ratios for the specimens is approximately 16 to 1. Specimens are loaded at their mid-span. Stress levels and test temperatures are determined according to intended uses.

The second identified specification is an ASTM draft specification. The draft specification proposes standard test methods for determination of flexural creep of plastic lumber and shapes under specific environmental conditions. This ASTM specification suggests using a four-point loading for flexural creep tests. Test specimens in the form of a right prism and full sections of manufactured plastic lumber or shape are used. Unless actual conditions warrant otherwise, test temperatures of 10 EC (50 EF), 23 EC (73 EF), and 40 EC (104 EF) are recommended. The stress levels are determined according to the intended use of the test results. It is recommended that measurements be made in accordance with the following approximate time schedule: 1, 6, 12, and 30 minutes; 1, 2, 5, 20, 50, 100, 200, 500, 700, and 1000 hours.

4.6.2 Laboratory Procedure

To evaluate time dependent behavior of available recycled products, a cantilever flexural creep test was utilized. This method was employed over the four-point bend test because it more accurately reflects likely field applications. Additionally, recommended span to thickness ratios could not be met with provided specimens. It should be noted that similar test setups have been used successfully in numerous previous TTI projects. In one such project recycled sign supports were subjected to static loads at sign mounting height to assess the buckling performance of posts (Alberson, 1993).

Whenever possible, researchers used full-size as-manufactured test specimens. Due to variations in received specimens, the length of the specimens varied between 1800 to 2100 mm (6 to 7 ft). The creep test procedures were identical for both the qualified guardrail post and sign support specimens to obtain comparable results. Creep behavior is not a concern for offset blocks. Three representative samples were tested for each product.

Creep tests were performed in a temperature controlled chamber. Figure 11 shows a typical temperature chamber setup used in the creep test. The temperature of the chamber was set at 40 EC as suggested by the specification. This temperature will cause the greatest creep since plastics experience more creep with increasing temperatures. High creep values were anticipated in the tests. Therefore, the flexural stress level was set at 690 MPa (0.1 ksi) to minimize excessive deformation that would exceed the deflection capacity of the test apparatus. The flexural stress level was kept constant for both sign supports and guardrail posts for comparison purposes. The required tip load was calculated by the formula given in **Eq. (2)**.

$$P = \sigma I / L c \qquad \textbf{Eq. (2)}$$

where σ = flexural stress at point of support, Pa (psi); I = moment of inertia of a cross section, mm^4 (in^4); L = support span, mm (in); and c = distance between neutral axis to the farthest fiber of specimen, mm (in).

Deformations were measured using a dial gage with a 0.25 mm (0.01 in) accuracy and 51 mm (2 in) stroke was used. The fixture was designed and built for the flexural creep test.

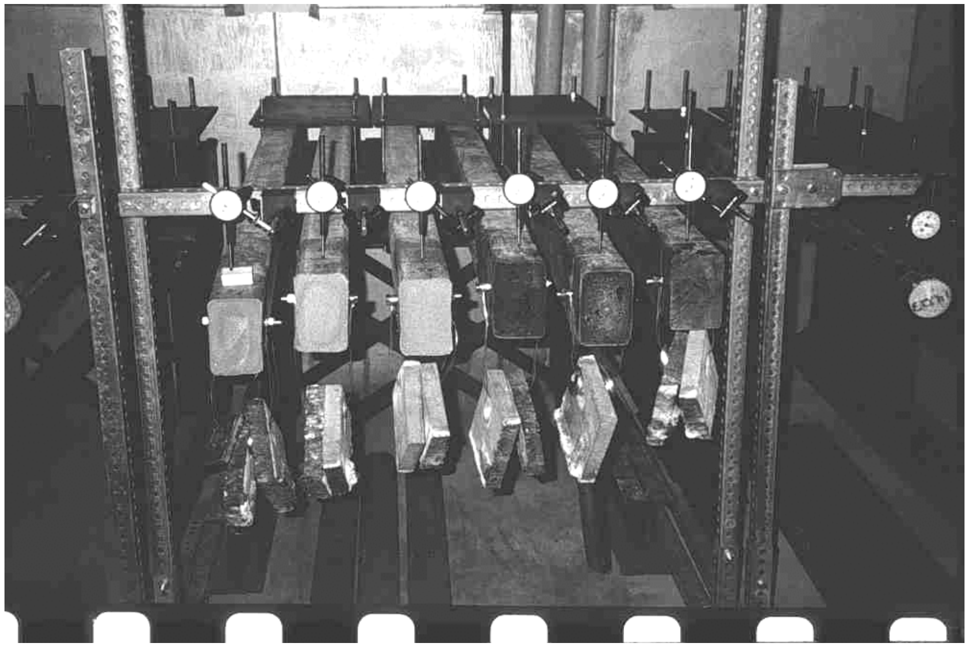

Figure 11. Flexural Creep Test Setup.

Researchers inserted specimens into the creep fixture as shown in Figure 11**.** The fixture was held horizontal and fixed against rotation. A minimum insertion length of 559 mm (22 in) was required to secure the specimen into the fixture. A vertical concentrated load was applied at a distance of 1219 mm (4 ft) from the fixed point. This length was used to accommodate the length limitations in received specimens. Calculated weights were attached to pre-drilled holes located 51 to 76 mm (2 to 3 in) from the tip of the specimens. All specimens were supported before the test began and dial gages were zeroed before the removal of supports.

As recommended by the specifications, the measurements were made in accordance with the following approximate time schedule: 1, 6, 12, and 30 minutes; 1, 2, 5, 20, 50, 100, 200, 500, 700, and 1000 hours. For most specimens, readings ceased at 240 minutes due to the limited time for the overall testing program. However, the test data curve was used to project the value out to 1000 hours. The results obtained and the accuracy of the data are discussed in Chapter V.

4.7 WARPAGE

To satisfy the service requirements and provide maximum information to drivers, roadside safety devices should always remain straight and visible. To achieve this requirement, a series of warpage tests was conducted to assess deformation characteristics of recycled materials when subjected to environmental conditions. Since slender members are more prone to warp, tests were conducted only on candidate sign supports.

4.7.1 Existing ASTM Standards

No ASTM standard was identified addressing a warpage test. It should be noted that previous warpage tests were conducted on recycled plastics by Oregon DOT. However, no information was given about details of the test. Therefore, for assessment of the warpage behavior of the recycled materials, a simple test setup was developed.

4.7.2 Laboratory Procedure

Researchers installed specimens at Texas A&M Riverside campus facilities in an open field to observe their warpage behavior. Figure 12 shows the sign supports subjected to warpage tests. The lengths of specimens ranged between 1800 to 2100 mm (6 to 7 ft). Steel casings (shown in Figure 13) were used to secure the specimens in the ground. To quantify the warpage, deflection of posts relative to a vertical plane was measured. To account for three-dimensional movement, the measurements were made on two adjacent sides. Three representative samples were used on all products. The readings were taken periodically for a six month period, including the summer months to insure maximum warpage.

Figure 12. Warpage Test Setup.

Figure 13. Steel Casing Used for Warpage Test Specimens.

CHAPTER V - RESULTS OF MATERIAL EVALUATION

In this phase of the project researchers conducted a large testing program in accordance with the test procedures described in the preceding chapter. The purpose of the test program was to:

- determine the fundamental properties of the selected recycled materials,
- make comparisons among the various candidate recycled materials for each application,
- assess the compliance of the recycled materials and products to the nationally recognized performance standards, and
- recommend the most promising products for the next phase of this project.

To achieve the objectives stated above, a total of seven types of tests were conducted. These tests include: 1) static laboratory tests such as flexure, compression, density, and creep; 2) environmental exposure tests such as warpage and freeze/thaw; and 3) dynamic tests such as pendulum.

Test results of the recycled products showed a wide range of behavior due to the different material compositions. To help assess performance and evaluate the adequacy of these recycled materials, conventional materials that have been shown to meet nationally recognized performance standards were used as a baseline. Some mechanical properties of the recycled materials and products did not compare favorably to the baseline materials. For example, the stiffness was much lower for the recycled products, and the tendency to creep was much greater. However, a number of products displayed satisfactory performances for different application types.

This chapter provides a comprehensive summary of the results obtained from the laboratory and field tests for both the recycled and conventional materials. The results are presented by type of application. The conclusions drawn from these results as well as the recommendations for the next phase of the study are presented in the subsequent chapters.

5.1 GUARDRAIL POSTS

5.1.1 Flexure

Table 7 summarizes the results obtained from cantilever flexure tests conducted on candidate guardrail posts. Load-deflection curves and other additional information for these tests are available from TTI. Since sufficient flexural strength is a basic requirement for strong guardrail posts, the cantilever flexural test was used as a means to screen and select products for further testing and evaluation. The relative performance of the various recycled guardrail post candidates is assessed through comparison with conventional guardrail posts. A 184 mm (7.25 in.) diameter round wood post, which is the most commonly used guardrail post in Texas, was selected as the baseline for comparison purposes. Table 7 presents the comparison as a percent difference in maximum load, deflection at maximum load, and absorbed energy. Positive values indicate the recycled product had a higher value than the baseline wood post. Negative values indicate the recycled product had a lower value than the baseline wood post. To provide a more uniform evaluation among guardrail posts, the cantilever flexure tests were conducted until the recycled post deflected 305 mm (12 in) or failed. Elastic stiffness values were determined from the initial slope of the load-deflection curve. In addition to the 184 mm (7.25 in) diameter wood guardrail post, test results for conventional 152 mm ς 203 mm (6 ς 8 in) rectangular wood post and W150ς13.5 (W6ς9) structural steel post are also shown.

In the cantilever test performed at room temperature, most specimens failed in flexure on the tension face adjacent to the edge of the fixed support. Figure 14 shows a typical failure pattern. Some specimens, particularly those reinforced with steel rebars, did not exhibit brittle fracture, but rather continued to deform plastically at or near the maximum load (see Figure 15). For those members, the tests ceased when a deflection of 380 mm (15 in) was reached. A sample of recorded data is shown in Table 34 and Figure 50 of Appendix B.

The maximum average loads measured for all recycled products ranged from 3.38 kN (0.76 kips) for specimen 30.C.1 to 117.25 kN (26.4 kips) for specimen 14.C.2. The average maximum load for the round wood specimens was 56.58 kN (12.7 kips). This strength requirement was used as the initial screening criterion for the recycled guardrail post candidates. As shown in Table 7, the flexural capacity of specimens 3.C.3, 3.C.4, 3.C.5, 14.C.3, 20.C.2, 20.C.4, 20.C.5, 20.C.6, 20.C.8, 20.C.9, and 26.C.2 exceeded that of the baseline post. This observation is further illustrated in Figure 16. Additional posts from among those passing the initial screening were eliminated from further consideration based on size, weight, and/or cost. Excessive size and weight make the candidate posts impractical from a shipping, handling, and installation standpoint. Further, these posts, as well as some others with a high percentage of reinforcing materials, were also impractical due to high material and fabrication costs, which resulted in products that cost many times higher than conventional guardrail posts. Based on these criteria, researchers selected guardrail post specimens 3.C.3, 3.C.4, 14.C.3, 20.C.8, and 20.C.9 as the most promising for further testing and evaluation under this study. Comparison of energy dissipated by the candidate guardrail posts during the cantilever flexure tests is shown in Figure 17.

Table 7. Summary of Cantilever Flexure Test Results for Guardrail Post Specimens.

Specimen Code	Member Size (mm x mm)	Max. Load (kN)	Max. Load Difference (%)	Deflection @ Max. Load (mm)	Deflection Difference (%)	Absorbed Energy (kN-mm)	Absorbed Energy Difference (%)
Wood-R	184 Dia.	57	0	104	0	3,479	0
Wood	150 x 200	76	34	86	-17	4,468	28
W6x9	100 x 150	64	13	55	-47	2,524	-27
W6x15	150 x 150	109	93	87	-17	12,259	252
3.C.1	125 x 180	40	-29	186	79	5,117	47
3.C.2	180 x 180	51	-10	217	108	7,223	108
3.C.3	133 x 184	53	-6	170	63	6,577	89
3.C.4	120 x 184	61	8	375	260	15,649	350
3.C.5	127 x 184	61	7	404	288	18,073	420
6.C.1	152 x 193	24	-58	277	166	4,928	42
14.C.1	175-Dia.	45	-21	91	-13	2,295	-34
14.C.2	273-Dia.	117	107	120	16	8,563	146
14.C.3	175-Dia.	61	8	115	10	3,973	14
17.C.1	160 x 200	40	-29	84	-20	1,904	-45
20.C.1	137 x 185	30	-47	390	275	7,735	122
20.C.2	140 x 191	69	23	291	180	18,244	424
20.C.3	185 x 185	42	-26	405	289	11,175	221
20.C.4	185 x 185	77	35	223	114	11,052	218
20.C.5	185 x 185	91	61	244	134	14,579	319
20.C.6	254-Dia.	68	20	413	296	19,479	460
20.C.7	140 x 190	44	-23	171	64	4,379	26
20.C.8	185 x 185	73	29	189	82	8,496	144
20.C.9	140 x 190	56	-1	243	134	9,975	187
20.C.10	140 x 190	34	-40	465	346	10,135	191
26.C.1	150 x 200	26	-54	49	-53	671	-81
26.C.2	250 x 250	69	22	69	-34	2,363	-32
26.C.3	250-Dia.	52	-9	88	-16	2,689	-23
28.C.1	130 x 190	35	-37	59	-44	1,105	-68
28.C.2	155 x 206	43	-24	67	-36	1,502	-57
30.C.1	175-Dia.	3.71	-93	140	34	366	-89
30.C.2	152 x 203	8	-87	60	-42	345	-90
31.C.1	175-Dia.	3	-94	202	94	530	-85
31.C.2	175-Dia.	5	-92	245	136	1,062	-69
31.C.3	175-Dia.	8	-86	323	210	1,917	-45
31.C.4	175-Dia.	9	-84	343	229	2,279	-34

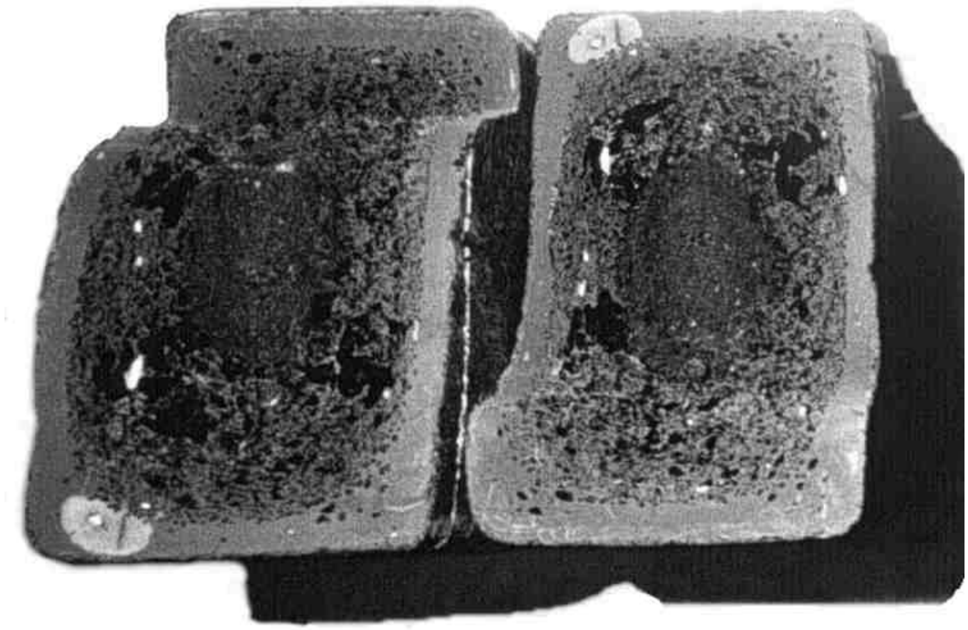

Figure 14. Typical Failure Pattern Observed for Guardrail Posts after Cantilever Flexure Test.

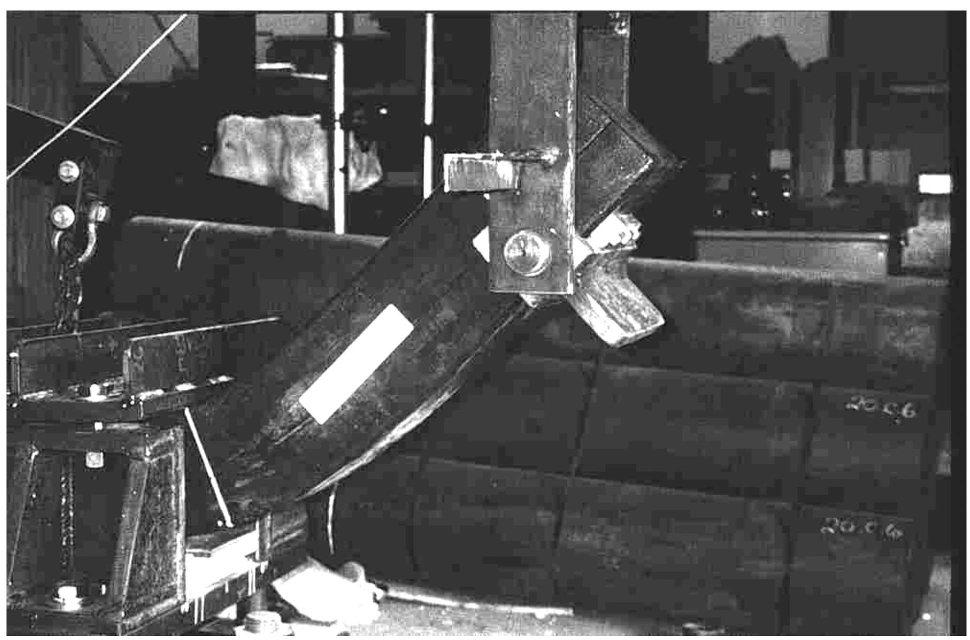

Figure 15. Excessive Deformation for Cantilever Flexure Test.

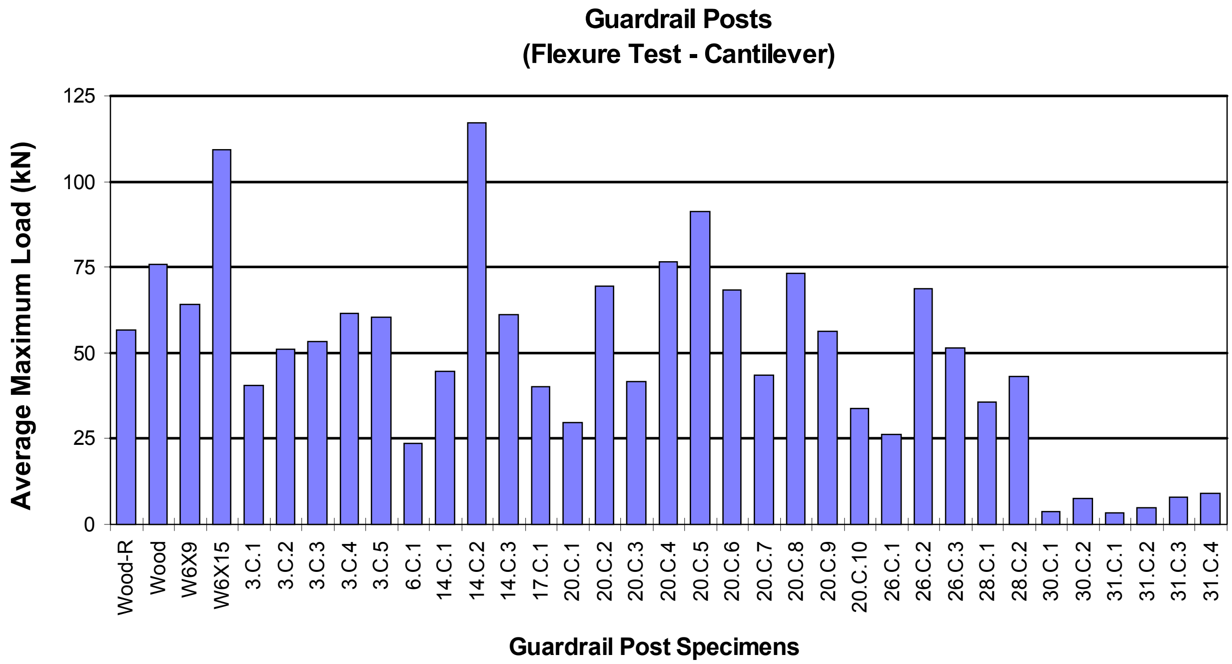

Figure 16. Average Maximum Load Comparison for Guardrail Posts at Room Temperature (23 EC (73 EF)).

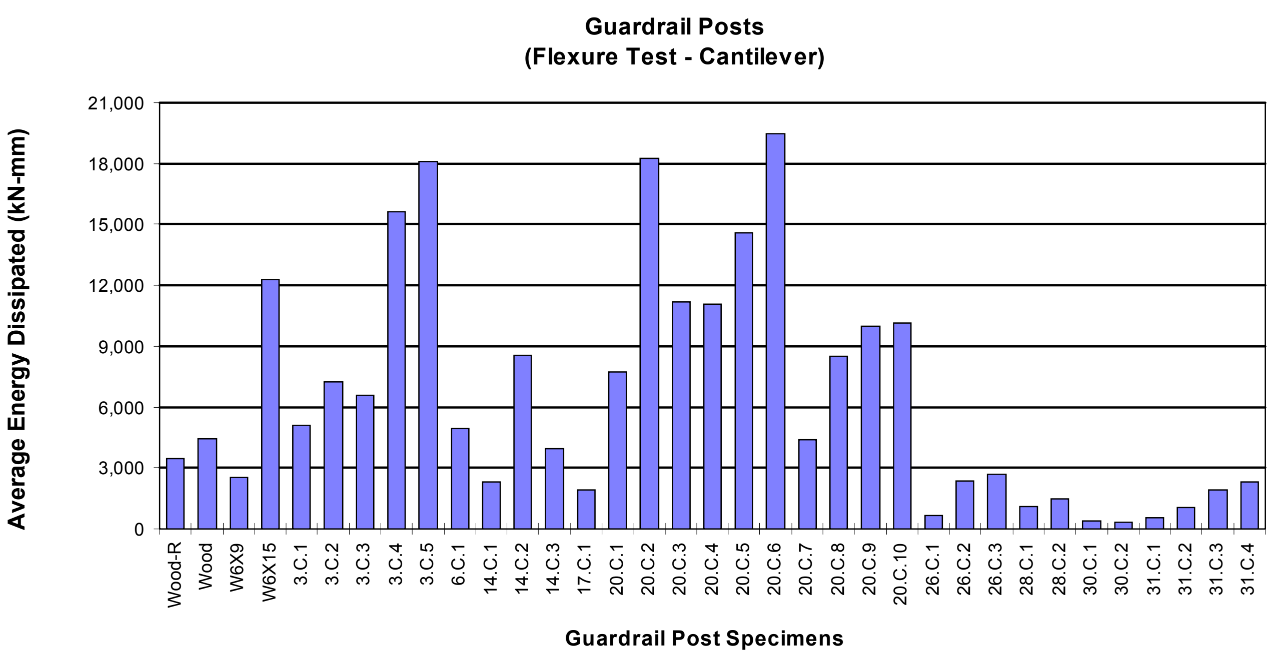

Figure 17. Average Energy Dissipation Comparison for Guardrail Posts at Room Temperature (23 EC (73 EF)) .

Full-scale specimens coupled with large deflections precluded TTI from determining the temperature effect in the cantilever test setup. To overcome this limitation, three-point bend tests were conducted. The additional flexural tests were performed at hot (50 ^{o}C (122 EF)), cold (0 ^{o}C (32 EF)), and room temperature (23 ^{o}C (73 EF) on previously qualified guardrail posts. A sample of recorded data can be found in Table 35 and Figure 51 in Appendix B. A summary of the three-point bend test results for hot, cold, and room temperatures is given in Table 8. Additional data on specific tests are available from TTI.

In Table 8, comparisons between recycled materials and conventional materials are given in terms of maximum load, absorbed energy, and initial stiffness. As in previous tests, the conventional 184 mm (7.25 in) diameter wood guardrail post was selected as the baseline. As shown in Table 8, temperature has a substantial effect on flexural behavior of guardrail posts. For instance, the increase in temperature from 0 ^{o}C (32 EF) to 120 ^{o}C (248 EF) led to a reduction as high as 69% in average load capacity (specimen 3.C.4). Figure 18 shows the observed trend for decreasing load capacity with increasing temperature for most of the recycled products. As expected, the load carrying capacity of the conventional W150ς13.5 (W6ς9) steel post did not change for different temperatures. Specimen 14.C.3 had a concrete core and as a result was unaffected by temperature. The reduction in dissipated energy with the increase in temperature is depicted in Figure 19. The effect of temperature on the initial stiffness of the guardrail post candidates is given in Figure 20. As shown in this figure, the conventional W150ς13.5 (W6ς9) steel post has the highest initial stiffness followed by specimen 14.C.3. As expected, there is a reduction in initial stiffness with increase in temperature for those specimens that are comprised predominantly of recycled plastics (e.g., 3.C.3, 3.C.4, and 20.C.9). At lower temperatures, the stiffness of these plastic posts is comparable to that of the 184 mm (7.25 in.) diameter wood post. At higher temperatures, the stiffness of these plastic posts is less than that of the conventional round wood post. This could potentially lead to higher dynamic guardrail deflections under impact loads. However, other variables affect the dynamic deflections of the guardrail as well, making it difficult to draw definitive conclusions in this regard.

Table 8. Summary of Three Point Bend Flexure Test Results for Guardrail Post Specimens.

Specimen Code	Member Size (mm x mm)	Average Load (kN)				Avg. Absorbed Energy (kN-mm)				Average Stiffness (kN/mm)			
		0 °C	23 °C	50 °C	% Change[A]	0 °C	23 °C	50 °C	% Change[A]	0 °C	23 °C	50 °C	% Change[A]
Wood	184 – Dia/	90	78	64	29	3,866	3,355	3,486	13	1.7	1.7	1.6	3
Wood	152 x 203	128	85	71	45	3,987	2,798	2,241	44	5.6	3.9	4.3	31
W6x9	102 x 152	80	78	78	2	1,024	1,209	1,541	34	11.9	10.8	10.5	11
3.C.3	133 x 184	77	50	28	64	5,879	3,911	2,091	64	2.0	1.3	0.8	58
3.C.4	121 x 184	67	40	21	69	5,060	2,852	1,447	71	1.1	0.7	0.3	70
14.C.3	171 - Dia.	75	79	72	9	1,715	2,411	1,766	29	8.6	2.9	6.7	66
20.C.9	140 x 191	84	59	44	48	7,014	5,214	3,868	45	2.5	1.7	1.2	50

A - percent change calculated based on sample maximum – minimum values

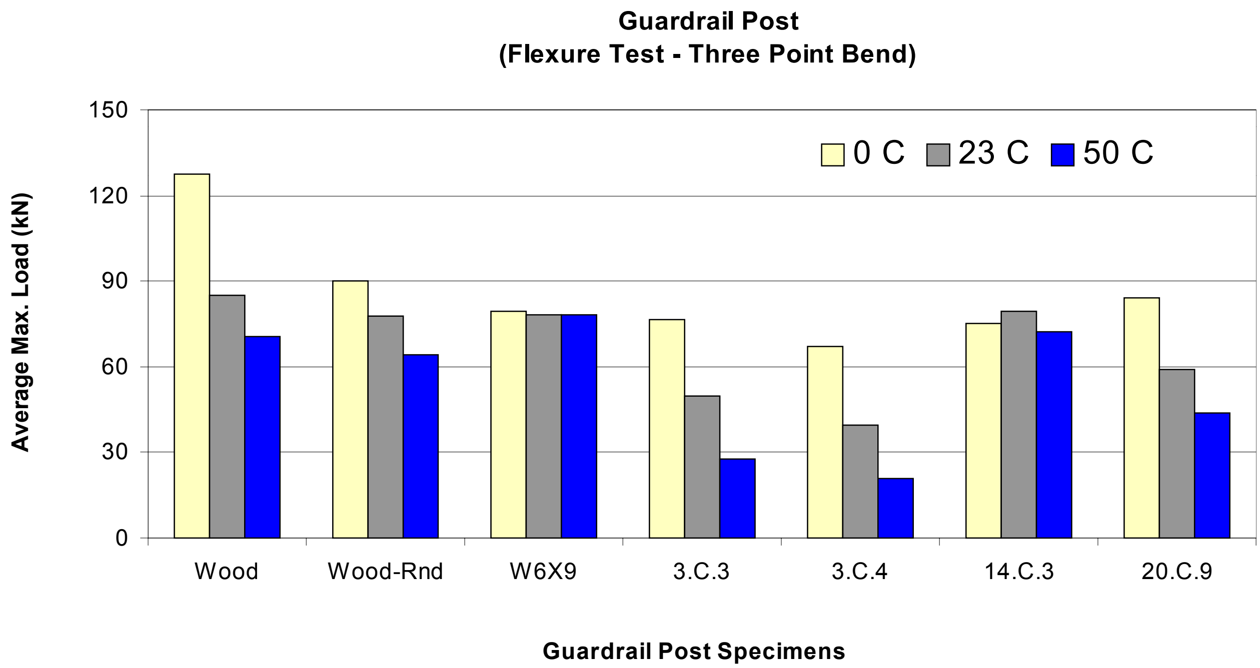

Figure 18. Effect of Temperature on Average Maximum Load of Guardrail Post Specimens.

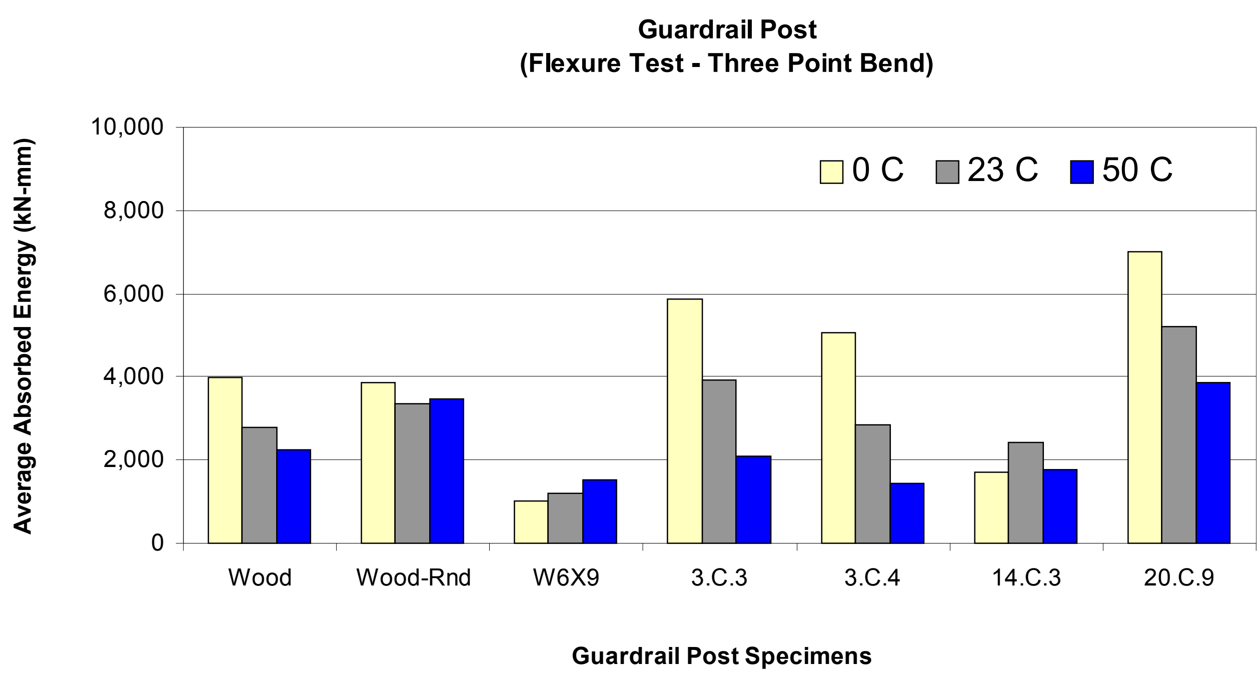

Figure 19. Effect of Temperature on Average Energy Dissipation of Guardrail Post Specimens.

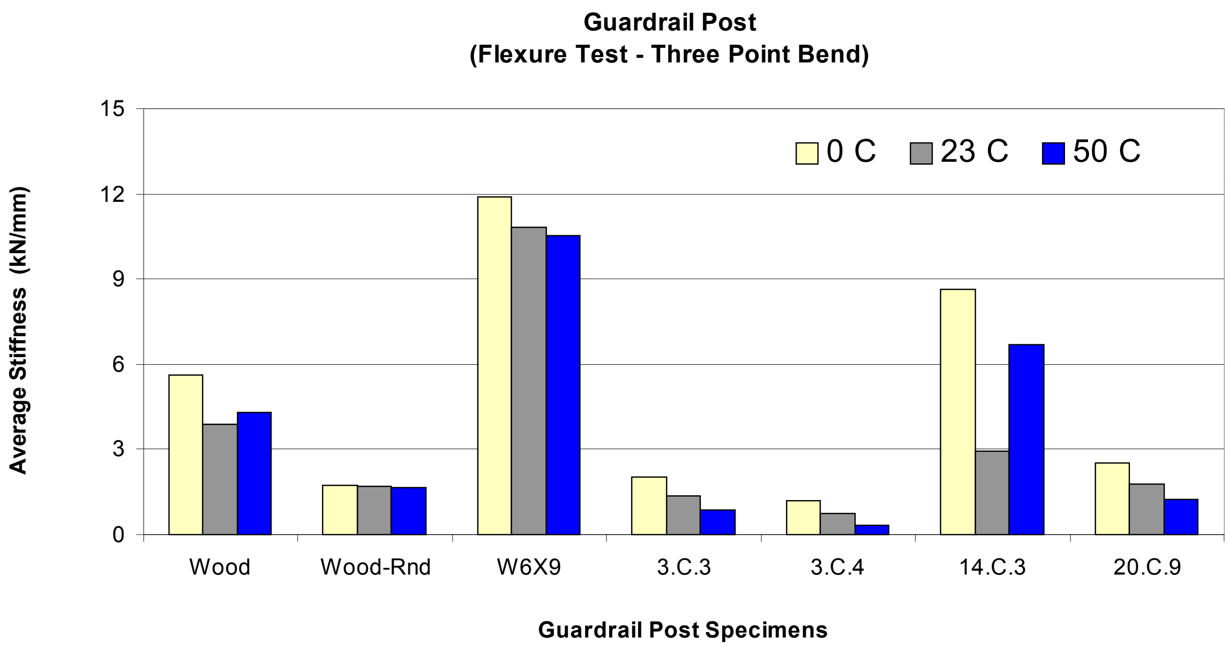

Figure 20. Effect of Temperature on Average Initial Stiffness of Guardrail Post Specimens.

For each candidate product, TTI conducted five tests to obtain an average response. The range of values observed in these tests provides some indication regarding the consistency and quality of the product. For most of the tests, results varied considerably even for pieces cut from the same specimens. After the visual inspection of the test samples, it was determined that the cross section of most of the recycled plastic products consisted of two distinct regions: a core region with air voids trapped during the manufacturing process and a denser shell that surrounds the core. A typical cross section is shown in Figure 21. As a general rule, specimens with smaller core regions were typically much stronger than specimens with larger core regions for same products (3.C.1-A and -C). Impurities were also a factor in reducing the bending strength of the recycled products. A summary table of core region and shell dimensions for guardrail specimens is given in Table 9.

Recycled materials consisting largely of polyethylene (PE) were prone to be more ductile than the other material compositions such as glass fiber or mixed strap. While energy absorption increases with increasing ductility, the associated excessive deflections can render some products unsuitable for use in highway safety appurtenances.

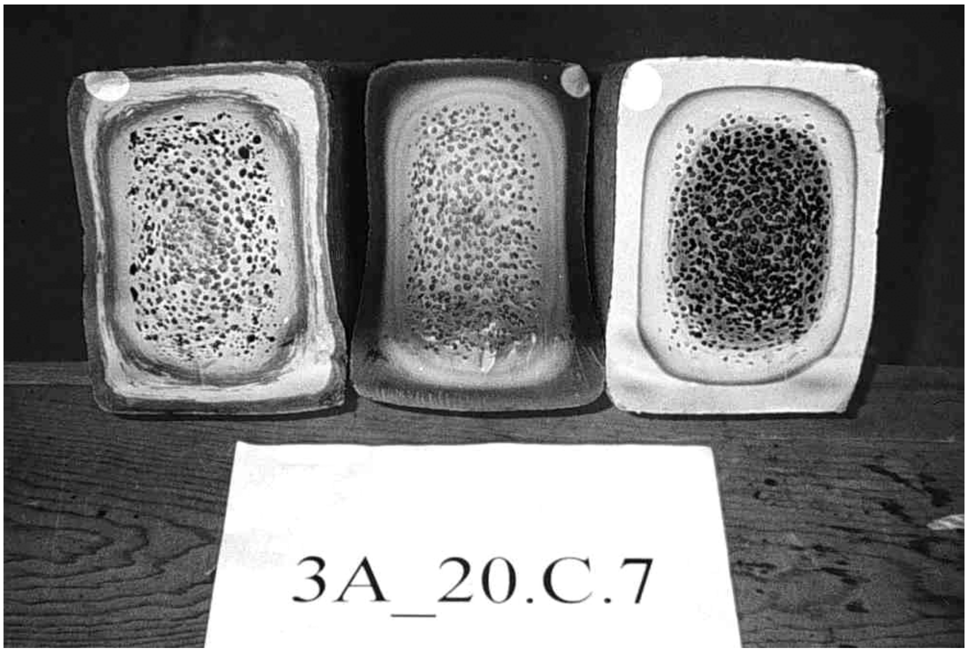

Figure 21. Typical Cross Section View of a Recycled Plastic Product.

Table 9. Core Region - Shell Dimension Comparison for Candidate Guardrail Posts.

Specimen Code	Shape	Dimensions (mm)		Manufacturing Process
		Overall	Core	
Wood-R	Circular	184	0	Southern Yellow Pine
Wood	Rectangular	150 x 200	0	Southern Yellow Pine
W6x9	W-shape	100 x 150	0	Structural Steel Shape
W6x15	W-shape	150 x 150	0	Structural Steel Shape
3.C.1	Rectangular	125 x 180	70 x 120	Molded
3.C.2	Square	180 x 180	130 x 130	Molded
3.C.3	Rectangular	133 x 184	80 x 130	Molded
3.C.4	Rectangular	120 x 184	70 x 100	Molded
3.C.5	Rectangular	127 x 184	70 x 100	Molded
6.C.1	Rectangular	152 x 193	0	Continuously Extruded
14.C.1	Circular	175 – Dia.	0	Concrete Filled Fiberglass Tube
14.C.2	Circular	273 – Dia.	0	Concrete Filled Fiberglass Tube
14.C.3	Circular	175 – Dia.	0	Concrete Filled Fiberglass Tube
17.C.1	Rectangular	160 x 200	110 x 140	Extruded
20.C.1	Rectangular	137 x 185	90 x 120	Extruded
20.C.2	Rectangular	140 x 191	90 x 120	Extruded
20.C.3	Square	185 x 185	120 x 120	Extruded
20.C.4	Square	185 x 185	100 x 100	Extruded
20.C.5	Square	185 x 185	120 x 120	Extruded
20.C.6	Circular	254 – Dia.	140 – Dia.	Extruded
20.C.7	Rectangular	140 x 190	70 x 130	Extruded
20.C.8	Square	185 x 185	150 x 150	Extruded
20.C.9	Rectangular	140 x 190	65 x 115	Extruded
20.C.10	Rectangular	140 x 190	90 x 130	Extruded
26.C.1	Rectangular	150 x 200	100 x 150	Continuously Extruded
26.C.2	Square	250 x 250	170 x 170	Continuously Extruded
26.C.3	Circular	250 - Dia.	150 – Dia.	Continuously Extruded
28.C.1	Rectangular	130 x 190	80 x 130	Molded
28.C.2	Rectangular	155 x 206	90 x 140	Molded
30.C.1	Circular	175 – Dia.	0	Plastic Filled Rubber Tube
30.C.2	Rectangular	152 x 203	0	Bonded Plastic Boards
31.C.1	Circular	175	0	Foam Filled Rubber Tube
31.C.2	Circular	175	0	Foam Filled Rubber Tube
31.C.3	Circular	175	0	Plastic Filled Rubber Tube
31.C.4	Circular	175	0	Plastic Filled Rubber Tube

5.1.2 Hydrothermic Cycling

The hydrothermic cycling process was performed to determine if the flexural strength of guardrail posts changed when subjected to freeze/thaw cycles. Five representative samples were tested for each product. The range of values observed in these tests again provides some indication regarding the consistency and quality of the product. A summary of the cantilever flexure test results on candidate guardrail posts before and after hydrothermic cycling process is given in Tables 10 and 11. The same results are given in Figures 22 and 23 as bar charts. Representative load-deflection curves for conditioned specimens and tables illustrating the results in greater detail are available from TTI. Sample data are shown in Table 36 and Figure 52 in Appendix B.

As seen from Figure 22, none of the candidate guardrail posts were appreciably affected by the hydrothermic cycling process. For specimens 3.C.3, 3.C.4, and 14.C.3, the hydrothermic cycling process has shown a slight increase in the average load. Since the increase in these specimens is within the standard deviation range, it can be concluded that freeze/thaw has no effect on those specimens. For specimen 20.C.9, the change was 4 percent showing the minor effect of hydrothermic cycling on that specimen. It can be concluded that in terms of strength all candidate guardrail posts were largely unaffected by the hydrothermic cycling process. The average energy dissipation of guardrail posts is shown in Figure 23. As noted, all of the specimens performed well and were not adversely influenced by the hydrothermic cycling.

Table 10. Effect of Hydrothermic Cycling on Load Capacity of Guardrail Post Specimens.

Specimen Code	Member Size (mm x mm)	No Conditioning		Hydrothermic Cycling		Change[A] (%)
		Average Maximum Load (kN)	Standard Deviation	Average Maximum Load (kN)	Standard Deviation	
3.C.3	133 x 184	53.4	7.1	63.3	5.8	19
3.C.4	120 x 184	57.9	2.5	58.4	1.0	1
14.C.3	175 - Dia.	61.3	1.8	65.0	2.0	6
20.C.9	140 x 190	55.9	5.3	53.3	2.3	-5

A – difference is computed relative to non-conditioned specimens

Table 11. Effect of Hydrothermic Cycling on Energy Absorption of Guardrail Post Specimens.

Specimen Code	Member Size (mm x mm)	No Conditioning		Hydrothermic Cycling		Change[A] (%)
		Average Absorbed Energy (kN-mm)	Standard Deviation	Average Absorbed Energy (kN-mm)	Standard Deviation	
3.C.3	133 x 184	6,557	1,730	11,826	3,294	80
3.C.4	120 x 184	15,649	1,401	11,771	319	-25
14.C.3	175 - Dia.	3,973	164	4,150	195	4
20.C.9	140 x 190	9,975	5,788	12,162	368	22

A – difference is computed relative to non-conditioned specimens

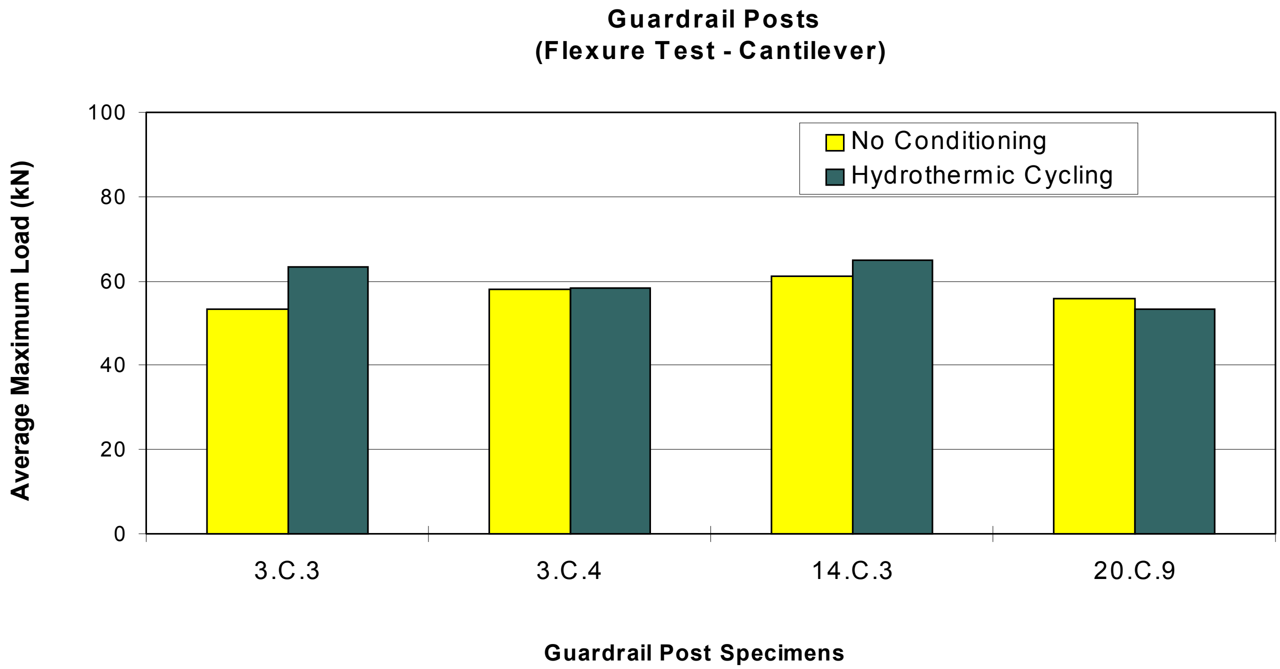

Figure 22. Effect of Hydrothermic Cycling Process on Average Maximum Load Capacity of Guardrail Post Specimens.

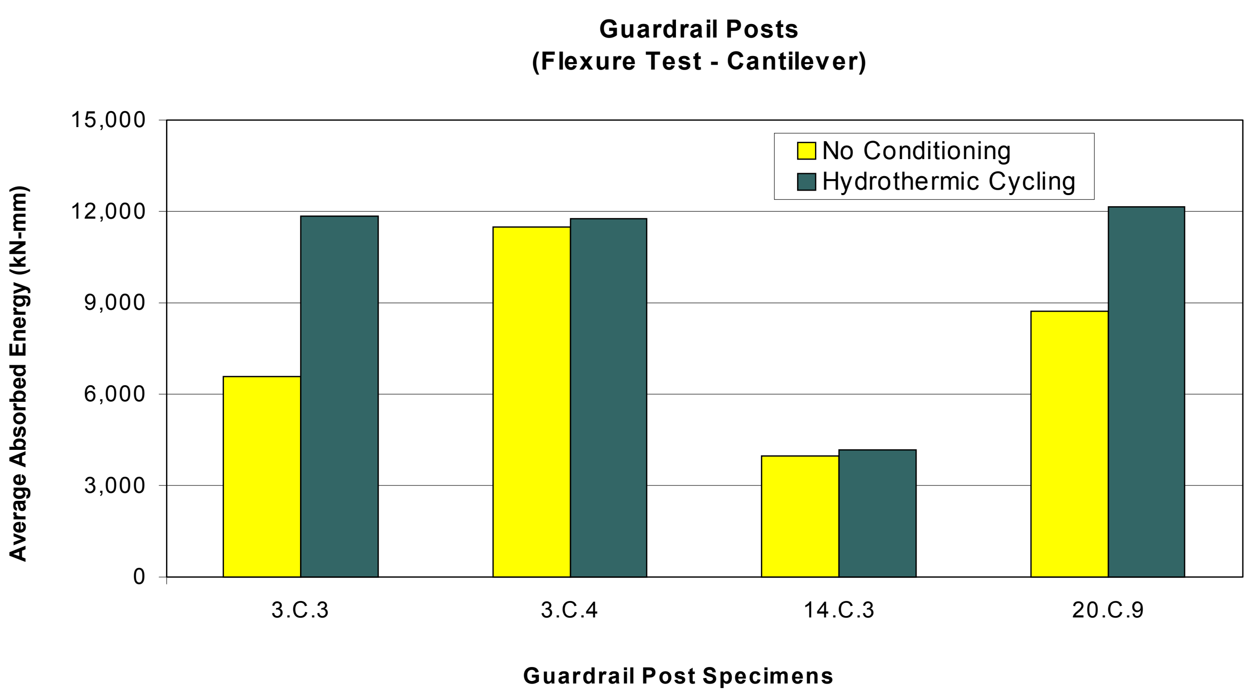

Figure 23. Effect of Hydrothermic Cycling Process on Average Energy Absorption of Guardrail Post Specimens.

5.1.3 Impact

A summary of the results from impact tests conducted on guardrail posts is shown in Table 12. Greater detail on the results is available from TTI. Impact tests were conducted only on qualified posts, those products whose flexural strength was comparable or better than baseline performances. Three representative samples were tested on each qualified post. The range of values observed in these tests provides some indication regarding the consistency and quality of the product. Impact tests were not performed on specimens 14.C.3, 20.C.8, and 20.C.9 due to unavailability. Thus, the impact test was only performed on specimens 3.C.3 and 3.C.4 along with the baseline posts. In Table 12, comparisons among recycled materials and conventional materials are given in terms of 10 ms average peak force that is exerted on specimens and absorbed energy during impact. The 10 ms average peak force was computed from the pendulum acceleration data. Force-deflection curves were generated and absorbed energy was calculated from the area under the curve. To provide a uniform evaluation basis among posts, the deflection was limited to 457 mm (18 in) or fracture of the post. A sample calculation of energy absorption is available from TTI. The conventional 184 mm (7.25 in) diameter wood guardrail post was selected as the baseline for comparison purposes. In addition, results on conventional 152 mm ς 203 mm (6 in ς 8 in) rectangular wood post and W150ς13.5 (W6ς9) structural steel post are also shown.

It should be noted that two different embedment depths were used to quantify the effect of embedment depth on the energy absorption capacity of the guardrail posts. The first set of impact tests was conducted with an embedment depth of 1118 mm (44 in). This is the embedment depth used by many states. All specimens fractured during the impact dissipating relatively small amounts of impact energy. To improve the absorbed energy of the posts, a shallower embedment depth was selected. A shallower depth shifted the failure mechanism from post fracture to soil yielding. Therefore, a second set of posts was tested with a 914 mm (36 in) embedment length. Unfortunately, specimen 3.C.4 was not available to be tested with the shallower embedment length. As expected, the dominant mode of failure was soil yielding as opposed to premature post fracture. In the second set of tests, the round wood specimens were tested with a typical Texas embedment of 965 mm (38 in).

Results obtained for both 1118 mm (44 in) and 914 mm (36 in) embedment lengths are shown in Table 12. An almost 175 percent increase was observed in the absorbed energy capacity for the round wood post when a shallower embedment was used. The increase in average energy absorbed, for the candidate guardrail posts as well as the baseline post, is depicted in Figure 24. The 10 ms average peak force exerted on the specimens is shown in Figure 25.

The maximum average absorbed energy measured for all recycled products ranged from 13 321 kN-mm (9.83 kip-ft) for specimen 3.C.4 to 14 284 kN-mm (10.54 kip-ft) for specimen 3.C.3. The average absorbed energy for the round wood specimen was 14,835 kN-mm (10.94 kip-ft). As shown in Figure 24, the energy absorption of specimens 3.C.3 appeared promising when compared to that of the baseline post. Sample data from pendulum testing is shown in Table 37 and Figure 53 in Appendix B.

Table 12. Impact Test Results for Guardrail Post Specimens.

Specimen Code	Member Size (mm x mm)	Embedment Depth (mm)	10ms Average Peak Force (kN)	Peak Force Difference[A] (%)	Energy Dissipated (kN-mm)	Dissipated Energy Difference[B] (%)
Wood-R	184 - Dia.	965[C]	62.2	0	5,393	175
Wood-R	184 - Dia.	1118	47.4	24	14,835	
Wood	152 x 203	914	62.0	0	9,579	42
Wood	152 x 203	1118	67.8	-9	13,623	
W6x9	102 x 152	1118	53.4	14	14,631	N/A
3.C.3	133 x 184	914	58.7	6	8,625	66
3.C.3	133 x 184	1118	60.4	3	14,284	
3.C.4	120 x 184	914	55.1	11	13,321	N/A

A – difference was calculated based on performance of round wood post (Wood-R)
B – calculation was made based on sample maximum-minimum values
C – 965 mm embedment length is typical for round wood post in the state of Texas

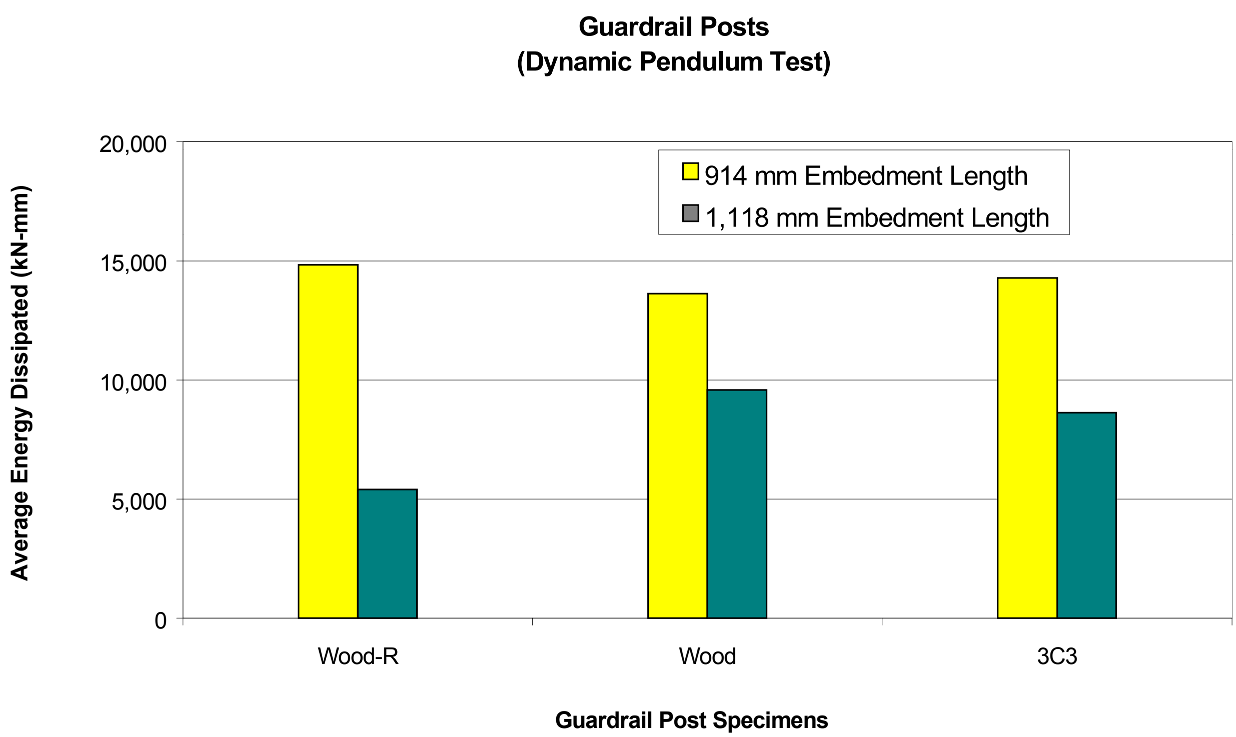

Figure 24. Effect of Embedment Depth on Energy Absorption of Guardrail Post Specimens.

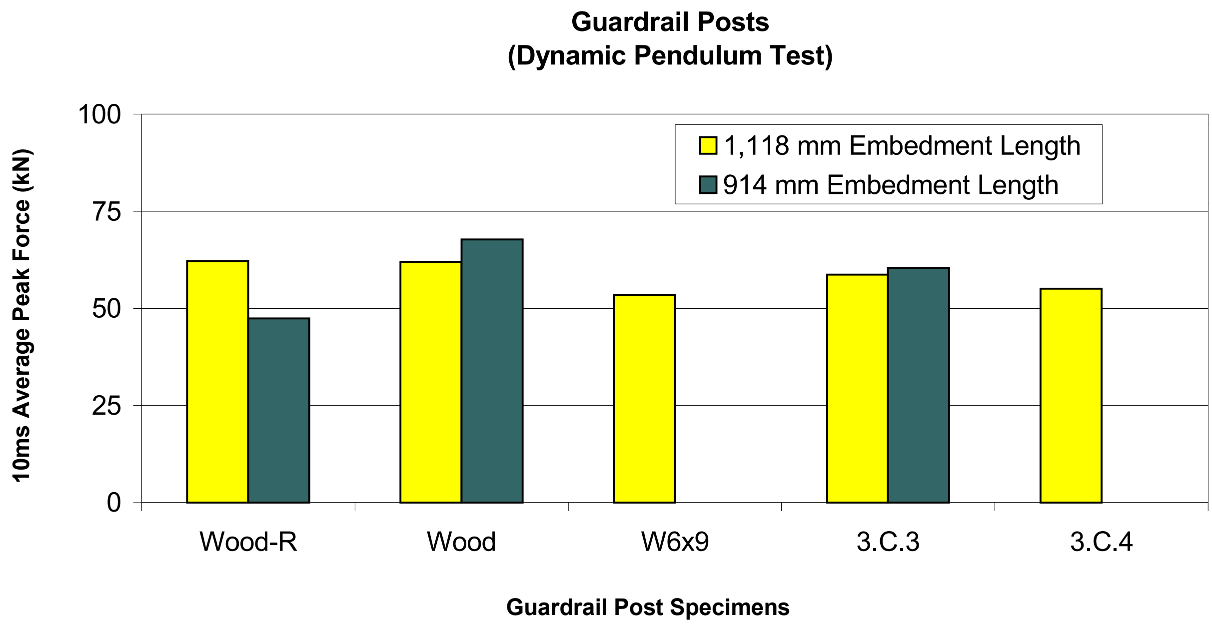

Figure 25. 10 ms Average Peak Force Exerted on Guardrail Post Specimens.

5.1.4 Density

A summary of the relative densities for the candidate and baseline guardrail posts is given in Table 13. A 152 mm ς 203 mm ς 356 mm (6 in ς 8 in ς 14 in) No.1 Douglas Fir type wood specimen with a relative density of 450 kg/m^3 (28 lb/ft^3) was used as the baseline. As noted from Table 13, only the qualified posts were considered. To determine an average response and obtain some insight about the materials' consistency and quality, three representative samples were tested. Unfortunately, the relative density was not determined for the specimen 20.C.9 due to difficulties involved in cutting representative samples. Thus, the densities were only obtained for specimens 3.C.3, 3.C.4, 14.C.3, and 20.C.8. Relative density of candidate guardrail posts ranged from 803 kg/m^3 (50 lb/ft^3) for specimen 3.C.3 to 2154 kg/m^3 (134 lb/ft^3) for specimen 14.C.3 showing them to be twice as dense as the wood. The relative density results are also shown in Figure 26.

Table 13. Relative Density Test Results for Guardrail Post Specimens.

Specimen Code	Specimen Size (mm x mm x mm)	Specific Gravity a / (a + w ! b) (23/23 EC)	Relative Density[A] (kg / m^3)
Wood	152 x 203 x 356	0.45	450
3.C.3	133 x 184 x 356	0.81	803
3.C.4	120 x 184 x 356	0.91	910
14.C.3	175 – Dia.	2.16	2154
20.C.8	185 x 185 x 356	0.84	840

A–Relative Density = Specific Gravity * Density of Water
Density of Water = 997.6 kg/m^3

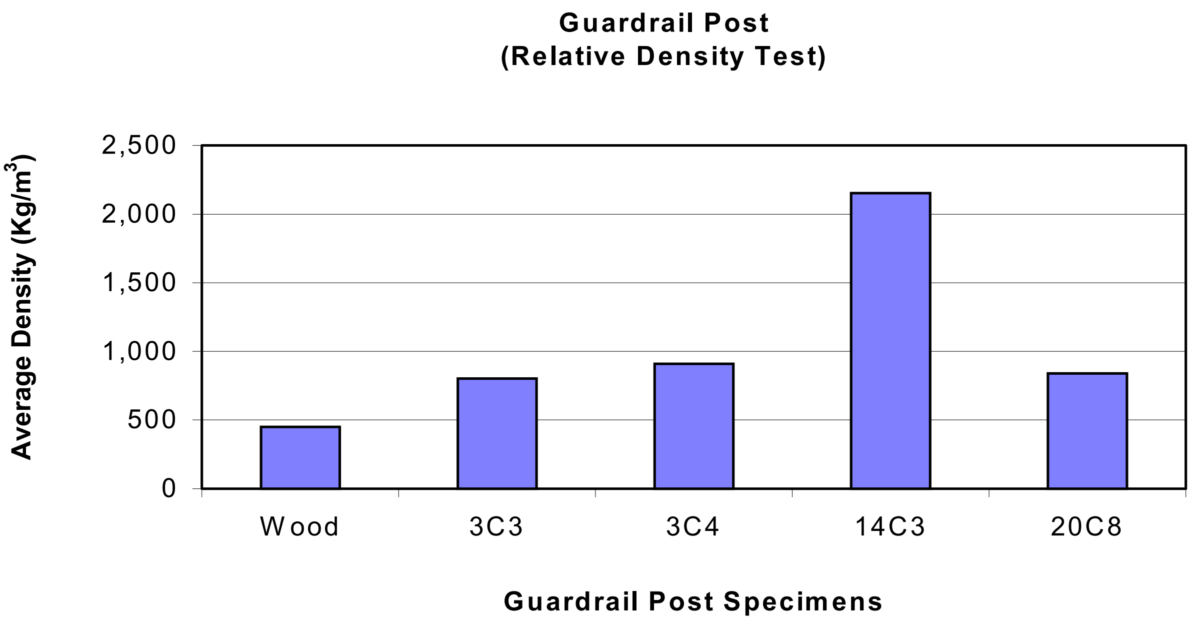

Figure 26. Relative Density Test Results for Guardrail Post Specimens.

5.1.5 Creep

A summary of the results obtained from creep tests conducted on candidate guardrail posts is shown in Table 14. As can be seen in the table, creep tests were conducted on only qualified posts. Additionally, the creep test was not performed on specimen 14.C.3 since this product was not susceptible to creep in previous tests. For each candidate three representative samples were subjected to creep. In Table 14, the average results for both recycled materials and conventional materials are given in terms of deflections and strains for initial, 240, and 1000 hours. The initial and 240-hour deflection measurements were based on dial gage readings. The projected 1000-hour deflection was predicted from the curve generated through the 240-hour test. The conventional 184 mm (7.25 in) diameter wood guardrail post was selected as the baseline for comparison purposes. In addition, results on conventional 152 mm ς 203 mm (6 in ς 8 in) rectangular wood post are also shown.

Comparisons of the average deflection measurements for the initial, 240- and 1000-hour readings are shown in Figure 27. Some of the initial deflections were as large as 6 mm (0.2 in), a magnitude two to three times that of the baseline post. Associated strain values for the same specimens are also shown in Figure 28. The strain values for recycled materials other than specimen 3.C.4 looked promising. However, for specimen 3.C.4 the calculated strain significantly exceeded the baseline post.

To provide a comparison and assess accuracy of the results for both real and projected values, specimen 3.C.3 was tested for 1000 hours. The results obtained are given in Figure 29 in terms of percent strain in log-log scale. The real and projected results showed good comparison. Thus it was concluded that projecting 1000 hour deflections was a reasonable approach. A sample of recorded data is shown in Table 38 and Figure 54 in Appendix B.

Table 14. Flexural Creep Test Results for Guardrail Post Specimens.

Specimen Code	Specimen Size (mm x mm)	Average Initial Deflection (mm)	Average Initial Percent Strain (%)	Average 240 hours Deflection (mm)	Average 240 hours Percent Strain (%)	Average 1000 hours Projected Deflection[A] (mm)	Average 1000 hours Projected Percent Strain[A] (%)
Wood-R	184 – Dia.	0.957	0.019	1.643	0.033	1.877	0.037
Wood	152 x 203	2.608	0.054	3.590	0.075	3.861	0.080
3.C.3	133 x 184	4.335	0.154	7.874	0.115	8.521	0.125
3.C.4	120 x 184	5.825	0.117	16.959	0.341	20.028	0.403
20.C.9	140 x 190	3.607	0.074	7.281	0.149	8.228	0.168

A – 240-hour data was used to obtain 1000-hour projected values

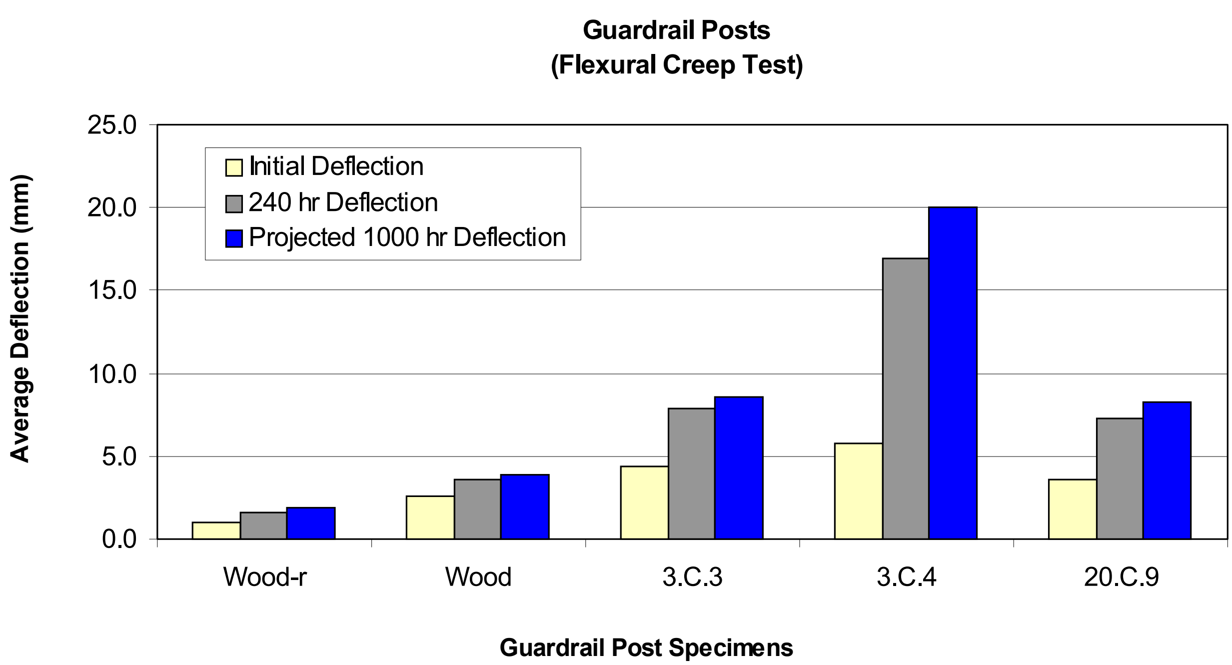

Figure 27. Average Flexural Creep Deflection Comparison for Guardrail Post Specimens.

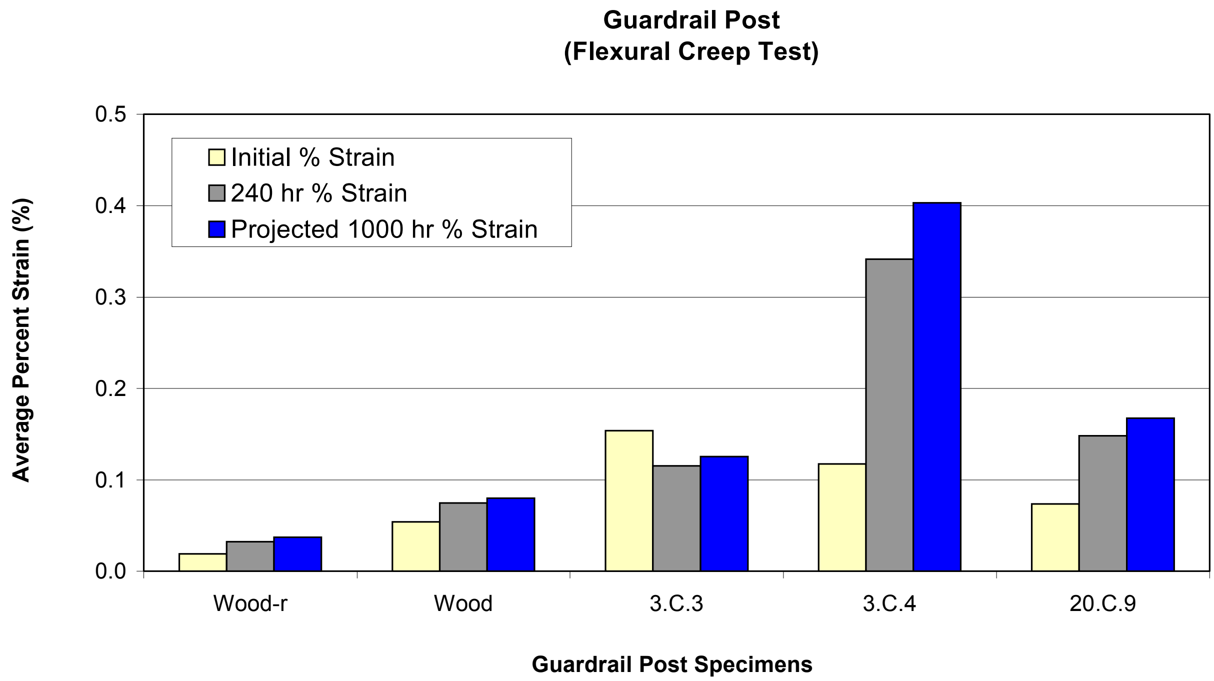

Figure 28. Percent Flexural Creep Strain Comparison for Guardrail Post Specimens.

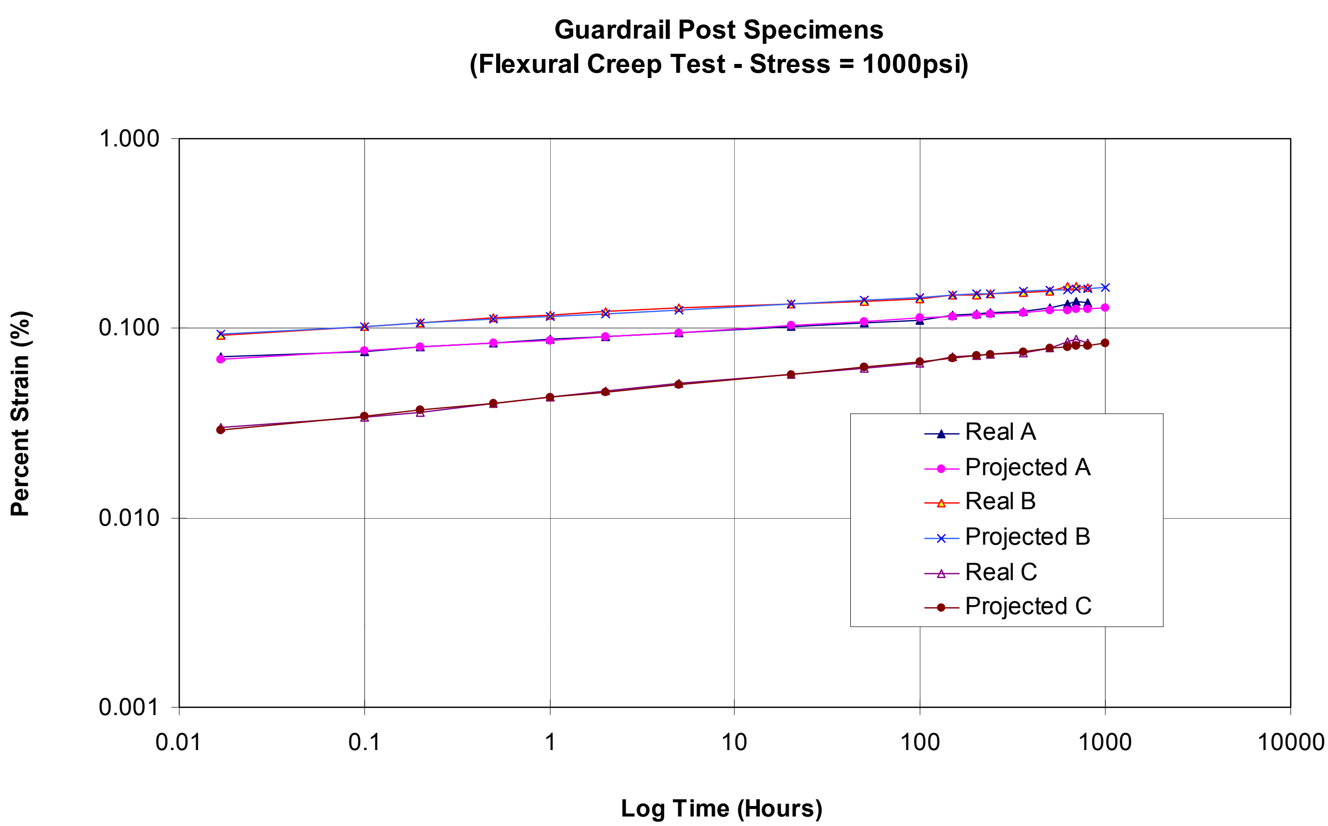

Figure 29. Real - Projected Percent Strain Comparison for Guardrail Post Specimens.

5.2 SIGN SUPPORTS

5.2.1 Flexure

A summary of the test results obtained from cantilever flexure tests conducted on sign support candidates is shown in Table 15. Representative load-deflection curves from these tests in greater detail are available from TTI. Similar to guardrail post results, comparisons between recycled materials and conventional materials are given in terms of maximum load, absorbed energy, and initial stiffness in Table 15. The energy was computed from the area under the load-deflection curve. To provide uniform evaluation among sign supports, the deflection was limited to 305 mm (12 in) or product failure. The initial elastic stiffness was the slope of the initial part of the load-deflection curve. The nominal 102 mm ς 102 mm (4 in ς 4 in) wood post was selected as the baseline for comparison purposes. Note that the actual dimensions of the surfaced wood post are 89 mm ς 89 mm (3.5 in ς 3.5 in).

Similar to the guardrail posts, the flexural tension face adjacent to the edge of the fixed support failed first for most sign supports. A cross sectional view of several sign support specimens with similar failure modes is shown in Figure 30. However, specimen 4.D.2 did not exhibit brittle fracture, but rather, continued to deform plastically at or near the maximum load. For those members, testing was stopped when a deflection of 305 mm (12 in) was reached.

Table 15. Cantilever Flexure Test Results for Sign Support Specimens.

Specimen Code	Member Size (mm x mm)	Max. Load (kN)	Max. Load Difference (%)	Deflection @ Max. Load (mm)	Deflection Difference (%)	Absorbed Energy (kN-mm)	Absorbed Energy Difference (%)
Wood	89 x 89	11.2	0	45	0	303	0
3.D.1	84 x 84	7.3	-35	225	398	1,176	288
4.D.1	89 x 89	5.8	-49	178	294	654	116
4.D.2	114 x 114	14.5	29	269	496	2,638	770
4.D.3	140 x 140	13.6	21	89	98	690	128
5.D.1	89 x 89	6.4	-43	111	146	427	41
5.D.2	89 x 140	10.0	-11	61	35	344	14
7.D.1	86 x 86	6.7	-41	130	189	553	82
7.D.2	89 x 137	15.5	38	164	263	1,725	469
7.C.1	137 x 140	20.9	86	108	139	1,336	341
8.D.1	91 x 91	5.6	-50	226	402	882	191
11.D.1	102 - Dia.	4.3	-62	158	249	448	48
14.D.1	102 - Dia.	21.2	89	72	59	815	169
14.D.2	114 - Dia.	16.0	21	78	74	607	100
14.D.3	76 - Dia.	7.8	-31	60	32	308	2
15.D.1	89 x 89	5.6	-50	158	250	574	89
17.D.1	89 x 89	7.5	-33	192	325	955	215
17.D.2	89 x 140	13.2	17	220	389	1,891	524
23.D.1	86 x 86	3.8	-66	79	75	184	-39
23.C.1	132 x 132	8.5	-25	51	14	259	-14
26.D.1	89 x 89	4.1	-63	58	29	168	-44
26.D.2	140 x 140	8.6	-23	30	-32	179	-41
28.D.1	89 x 89	6.9	-38	68	50	258	-15
32.D.1	94 x 94	7.1	-37	222	393	981	224

A – difference was computed relative to wood post

Figure 30. Typical Failure Pattern Observed for Sign Supports after Cantilever Flexure Test.

The maximum average loads measured for all recycled products ranged from 3.78 kN (849 lb) for specimen 23.D.1 to 21.21 kN (4768 lb) for specimen 14.D.1. The average maximum load for the baseline wood specimens was 11.24 kN (2528 lb). As illustrated in Table 15, the capacity of specimens 4.D.2, 4.D.3, 7.D.2, 7.C.1, 14.D.1, 14.D.2, and 17.D.2 was found to exceed that of baseline post. Although, performance of products 3.D.1, 5.D.2, 14.D.3, 17.D.1, 23.C.1, 26.D.2, 28.D.1, and 32.D.1 were found to be slightly lower than the baseline post, they are still considered promising. However, products 4.D.1, 5.D.1, 7.D.1, 8.D.1, 11.D.1, 15.D.1, 23.D.1, and 26.D.1 possessed very little flexural strength when compared to the remainder of the candidate sign supports. These results are graphically represented in Figure 31. The energy dissipated by the candidate sign supports during the cantilever flexure test is given in Figure 32. As can be seen in the figure, specimens 3.D.1, 4.D.1, 4.D.2, 4.D.3, 7.D.2, 7.C.1, 8.D.1, 14.D.1, 17.D.1, 17.D.2, and 32.D.1 consumed more energy than baseline posts. Also, the energy absorbed by specimens 5.D.1, 5.D.2, 7.D.1, 11.D.1, 14.D.3, 15.D.1, 23.C.1, and 28.D.1 were found to be comparable to that of baseline posts. Finally, specimens 23.D.1, 26.D.1, and 26.D.2 showed very little energy dissipation when compared to the remainder of the candidate sign supports.

To determine the effect of temperature on the flexural behavior of sign supports, researchers used a three-point bend test. The same procedure and temperature ranges used in the guardrail posts were utilized. A summary of the three-point bend test results for hot

(50 EC (122 EF)), cold (0 EC (32EF)), and room temperature (23 EC (73 EF)) are given in Table 16. Comparisons of recycled materials and conventional materials are given in terms of maximum load, absorbed energy, and initial stiffness. Again, a conventional wood post with nominal dimensions of 102 mm ς 102 mm (4 in ς 4 in) was selected as the baseline.

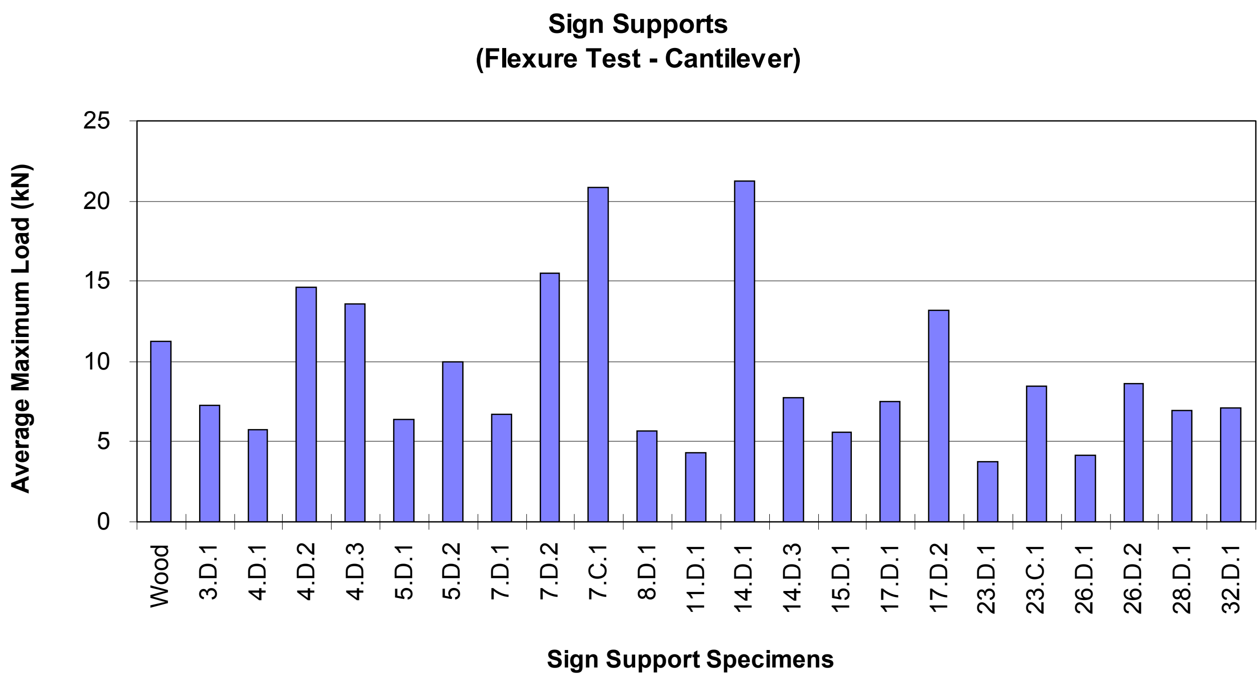

Figure 31. Average Maximum Load Comparison for Sign Supports at Room Temperature (23 EC) (73 EF).

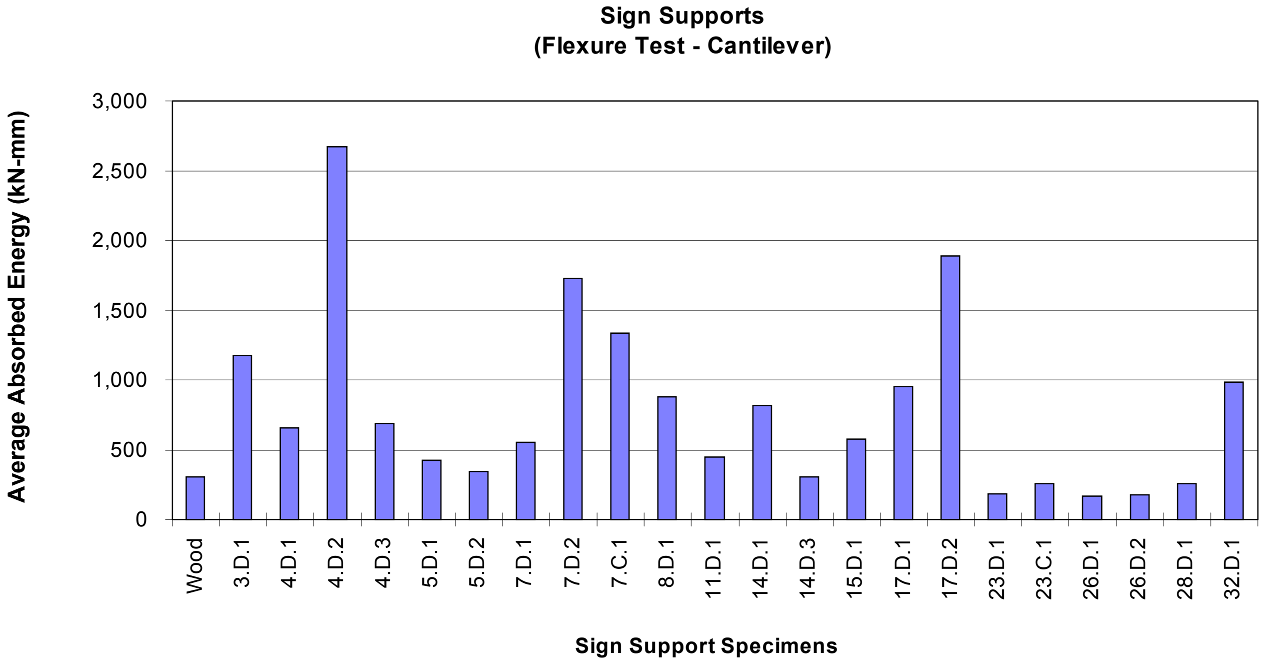

Figure 32. Average Energy Dissipation Comparison for Sign Supports at Room Temperature (23 EC) (73 EF).

As shown in Table 16, temperature has a substantial effect on flexural behavior of sign supports. For instance, the increase in temperature from 0 °C to 120 °C led to a reduction as high as 79 percent in average load capacity (specimens 4.D.1 and 4.D.2). Figure 33 shows the observed trend for decreasing load capacity with increasing temperature for candidate sign supports. It should be noted that only non-plastic products such as 14.D.1 and wood did not follow the same trend. A complete set of three-point bend test results is not available for specimens 5.D.1, 5.D.2, 8.D.1, and 7.C.1 due to the unavailability of those specimens. After the three-point bend test, specimen 14.D.1 seemed more promising than the other candidate sign supports. The performance of specimens 4.D.1, 8.D.1, 23.D.1, 26.D.1, 28.D.1, 17.D.2, 14.D.3, 23.C.1, and 26.D.2 was considered to be acceptable with respect to baseline results. Finally, compared to the other sign supports, large strength deterioration was observed for specimens 3.D.1, 7.D.1, 15.D.1, 17.D.1, 32.D.1, 7.D.2, 11.D.1, 4.D.2, and 4.D.3.

The absorbed energy for the candidate sign supports is shown in Figure 34. As shown in that figure, the amount of dissipated energy decreases when the temperature increases for most specimens. The average initial stiffness for guardrail posts is also given in Figure 35. It is obvious from the figure that the member initial average stiffness is inversely proportional with the increase in temperature. Other than specimen 23.C.1, all materials including recycled plastics and concrete follow the trend. However, it is still accurate to conclude that increase in temperature has a degrading effect on the stiffness of recycled materials, especially on recycled plastics.

For each candidate, five tests were conducted so the average response could be determined. The range of values observed in these tests provides some indication of the consistency and quality of the product. Furthermore, breakaway performance and flexural capacity are both critical to acceptable performance of sign supports, and both were investigated in this project. Results for impact performance and breakaway behavior for candidate sign supports is discussed in section 5.2.3.

After the flexure tests, as with the guardrail post specimens, specimens were visually inspected to assess the effect of cross-sectional pattern on strength of the material. The results were consistent with the guardrail post-test observations. In other words, the strength was found to be inversely proportional to the size of the core region (for example, specimens 5.D.2-A and -D). Existing impurities also reduced the flexural strength, particularly in materials manufactured with predominantly mixed scrap. A summary table showing the core region and shell dimensions for candidate sign supports is given in Table 17.

Table 16. Three-Point Bend Flexure Test Results for Sign Support Specimens.

Specimen Code	Member Size (mm x mm)	Average Load (kN)				Avg. Absorbed Energy (kN-mm)				Average Stiffness (kN/mm)			
		0 EC	23 EC	50 EC	% Change[A]	0 EC	23 EC	50 EC	% Change[A]	0 EC	23 EC	50 EC	% Change[A]
Wood	89 x 89	12.0	12.9	7.6	41	536	277	420	48	0.28	0.37	0.30	24
3.D.1	84 x 84	6.4	3.6	1.8	71	446	252	124	72	0.10	0.06	0.03	71
4.D.1	89 x 89	7.3	3.0	1.5	79	461	208	97	79	0.12	0.04	0.02	83
4.D.2	114 x 114	13.4	5.7	2.9	79	946	398	185	80	0.22	0.08	0.04	82
4.D.3	140 x 140	21.2	16.3	7.4	65	1073	1183	509	57	0.45	0.29	0.12	74
5.D.1	89 x 89	N/A	4.6	N/A	N/A	N/A	325	N/A	N/A	N/A	0.07	N/A	N/A
5.D.2	89 x 140	N/A	10.6	7.1	33	N/A	410	498	18	N/A	0.27	0.12	54
7.D.1	86 x 86	7.4	3.6	2.6	65	459	258	177	61	0.14	0.06	0.04	71
7.D.2	89 x 137	19.8	10.6	7.8	60	1078	779	541	50	0.47	0.19	0.13	72
8.D.1	91 x 91	N/A	2.6	1.3	49	N/A	194	89	54	N/A	0.04	0.02	52
11.D.1	102 - Dia.	4.1	3.1	1.5	63	276	231	98	65	0.06	0.05	0.02	68
14.D.1	102 - Dia.	24.6	27.4	19.7	28	706	816	484	41	0.77	0.74	0.65	16
14.D.3	76 - Dia.	13.9	11.9	7.0	49	586	454	174	70	0.34	0.21	0.20	41
15.D.1	89 x 89	5.7	3.1	1.4	75	403	224	96	76	0.09	0.05	0.02	77
17.D.1	89 x 89	5.8	3.4	2.2	63	403	242	153	62	0.09	0.05	0.03	65
17.D.2	89 x 140	13.8	8.1	4.5	67	1007	607	313	69	0.26	0.15	0.07	73
23.D.1	86 x 86	18.9	9.5	9.0	53	565	375	466	34	0.58	0.23	0.19	67
23.C.1	132 x 132	5.6	4.6	1.7	70	307	278	83	73	0.02	0.07	0.03	70
26.D.1	89 x 89	7.3	5.5	2.8	62	279	509	238	53	0.22	0.17	0.10	56
26.D.2	140 x 140	17.9	13.5	9.2	48	416	396	707	44	0.83	0.58	0.45	46
28.D.1	89 x 89	9.4	7.2	3.9	58	483	456	280	42	0.17	0.13	0.08	52
32.D.1	94 x 94	6.6	4.3	2.1	68	467	307	141	70	0.11	0.07	0.03	71

A–percent change was calculated based on sample maximum – minimum values

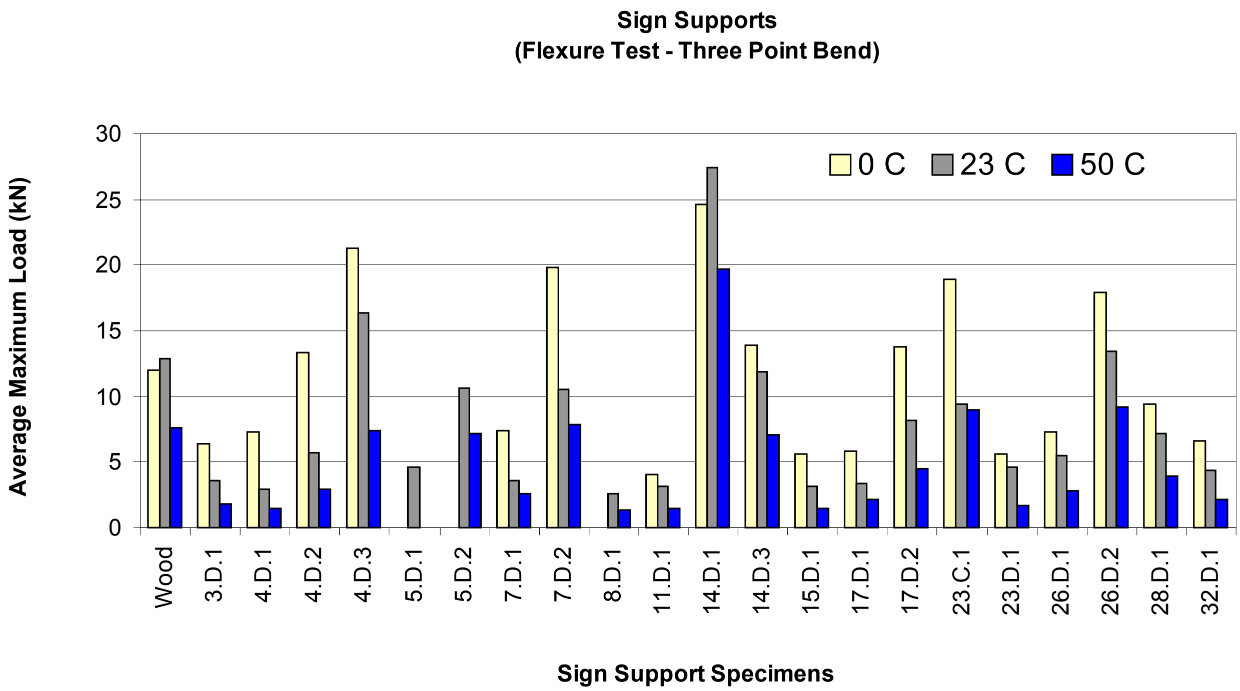

Figure 33. Effect of Temperature on Average Maximum Load of Sign Support Specimens.

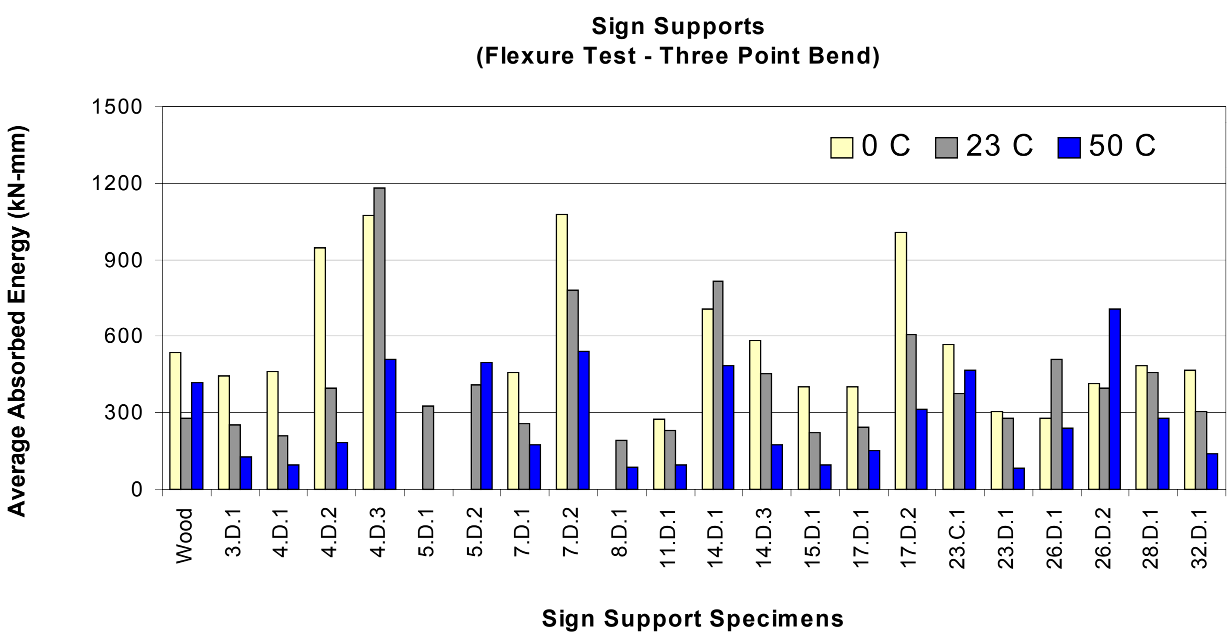

Figure 34. Effect of Temperature on Average Energy Dissipation of Sign Support Specimens.

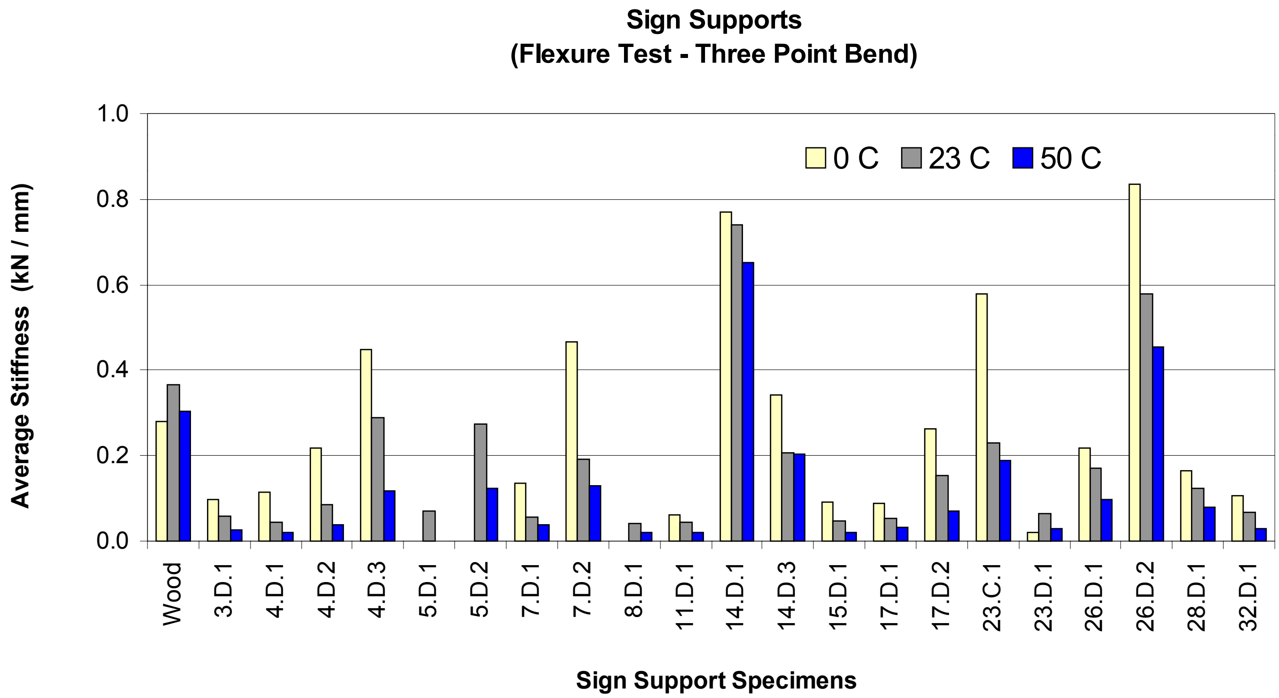

Figure 35. Effect of Temperature on Average Initial Stiffness of Sign Support Specimens.

Table 17. Core Regions - Shell Dimension Comparison for Sign Support Specimens.

Specimen Code	Shape	Dimensions (mm)		Manufacturing Process
		Overall	Core	
Wood	Square	89 x 89	0	Southern Yellow Pine
3.D.1	Square	84 x 84	60 x 60	Molded
4.D.1	Square	89 x 89	50 x 50	Extruded into Mold
4.D.2	Square	114 x 114	80 x 80	Extruded into Mold
4.D.3	Square	140 x 140	100 x 100	Extruded into Mold
5.D.1	Square	89 x 89	45 x 45	Extruded
5.D.2	Rectangular	89 x 140	40 x 90	Extruded
7.D.1	Square	86 x 86	60 x 60	Flow Molded
7.D.2	Rectangular	89 x 137	75 x 125	Flow Molded
7.C.1	Rectangular	137 x 140	100 x 100	Flow Molded
8.D.1	Square	91 x 91	0	Continuously Extruded
11.D.1	Circular	102 - Dia.	75	Extruded into Mold
14.D.1	Circular	102 - Dia.	0	Concrete Filled Fiberglass Tube
14.D.2	Circular	114 - Dia.	0	Concrete Filled Fiberglass Tube
14.D.3	Circular	76 Dia.	0	Concrete Filled Fiberglass Tube
15.D.1	Square	89 x 89	50 x 50	Extruded
17.D.1	Square	89 x 89	75 x 75	Extruded
17.D.2	Rectangular	89 x 140	75 x 130	Extruded
23.D.1	Square	86 x 86	50 x 50	Extruded into Mold
23.C.1	Square	132 x 132	80 x 80	Extruded into Mold
26.D.1	Square	89 x 89	60 x 60	Continuously Extruded
26.D.2	Square	140 x 140	100 x 100	Continuously Extruded
28.D.1	Square	89 x 89	65 x 65	Molded
32.D.1	Square	94 x 94	70 x 70	Molded

5.2.2 Hydrothermic Cycling

The hydrothermic cycling process was performed to determine the change, if any, in the flexural strength for the candidate sign supports when subjected to freeze/thaw cycles. For each candidate, five representative samples were tested to obtain an average. A summary of the cantilever flexure test results of candidate sign supports before and after hydrothermic cycling process is given in Tables 18 and 19. The average percent change for both maximum load and absorbed energy are calculated between the unconditioned and conditioned specimens. Graphical representations of the same results are shown in Figures 36 and 37. Representative load-deflection curves for conditioned specimens and the tables illustrating the results in greater detail are available from TTI.

As shown in Figure 36, most of the candidate sign supports were unaffected by the hydrothermic cycling process. For specimens 3.D.1, 4.D.1, 4.D.3, 7.D.1, 11.D.1, 14.D.3, and 26.D.2, the hydrothermic cycling process has shown an increase in average load. Since the increase is within the standard deviation, it can be concluded that freeze/thaw has no effect on these specimens. Additionally, the flexural capacity change in specimens 5.D.1, 5.D.2, 7.C.1, 8.D.1, 15.D.1, 17.D.1, 17.D.2, 23.D.1, 26.D.1, 28.D.1, and 32.D.1 was minimally affected by hydrothermic cycling. However, the strength deterioration observed for specimens 4.D.2, 7.D.2, and 23.C.1 was larger than strength deterioration observed for the other candidate sign supports. Specimens 14.D.1 and 14.D.2 were not run for this series of tests. Behavior is expected to be similar to 14.D.3.

The average energy dissipation of candidate sign supports is shown in Figure 37. Note that this figure and Figure 36 are similar in terms of performances. In other words, the sign supports considered promising in terms of load capacity were also found to be acceptable for energy dissipation. This also suggests hydrothermic cycling process has little effect on most of the candidate sign supports in terms of both load capacity and absorbed energy.

Table 18. Effect of Hydrothermic Cycling on Load Capacity of Sign Support Specimens.

Specimen Code	Member Size (mm x mm)	No Conditioning		Hydrothermic Cycling		Change[A] (%)
		Average Maximum Load (kN)	Standard Deviation	Average Maximum Load (kN)	Standard Deviation	
Wood	89 x 89	11.2	1.8	10.4	3.5	-8
3.D.1	84 x 84	7.3	1.6	9.2	2.0	27
4.D.1	89 x 89	5.8	0.4	5.9	0.4	2
4.D.2	114 x 114	14.6	0.9	11.0	1.0	-25
4.D.3	140 x 140	13.6	1.4	19.0	0.7	40
5.D.1	89 x 89	6.4	0.3	5.9	0.5	-7
5.D.2	89 x 140	10.0	1.7	9.6	2.0	-4
7.D.1	86 x 86	6.7	0.8	7.3	0.7	9
7.D.2	89 x 137	15.5	3.7	12.8	1.6	-17
7.C.1	137 x 140	20.9	1.7	18.6	2.6	-11
8.D.1	91 x 91	5.6	0.5	5.6	0.7	-1
11.D.1	102 - Dia	4.3	0.5	4.4	0.3	3
14.D.3	76 - Dia	7.8	0.8	9.0	0.3	16
15.D.1	89 x 89	5.6	0.3	4.5	0.7	-20
17.D.1	89 x 89	7.5	0.5	7.2	0.1	-4
17.D.2	89 x 140	13.2	1.7	11.8	2.9	-10
23.D.1	86 x 86	3.8	1.2	3.4	1.0	-9
23.C.1	132 x 132	8.5	1.5	6.2	1.2	-27
26.D.1	89 x 89	4.1	0.6	3.8	0.4	-8
26.D.2	140 x 140	8.6	0.6	9.1	0.4	5
28.D.1	89 x 89	6.9	0.4	5.8	0.5	-17
32.D.1	94 x 94	7.1	0.9	6.6	0.4	-7

A – difference is computed relative to non-conditioned specimens

Table 19. Effect of Hydrothermic Cycling on Energy Absorption of Sign Support Specimens.

Specimen Code	Member Size (mm x mm)	No Conditioning		Hydrothermic Cycling		Change[A] (%)
		Average Absorbed Energy (kN-mm)	Standard Deviation	Average Absorbed Energy (kN-mm)	Standard Deviation	
Wood	89 x 89	303	83.4	654	368	116
3.D.1	84 x 84	1176	386.3	1952	778	66
4.D.1	89 x 89	654	173.9	762	135	16
4.D.2	114 x 114	2676	491.4	2146	440	-20
4.D.3	140 x 140	690	194.5	1476	60	114
5.D.1	89 x 89	427	58.3	385	79	-10
5.D.2	89 x 140	344	106.8	365	137	6
7.D.1	86 x 86	553	134.2	657	145	19
7.D.2	89 x 137	1725	1183.0	854	247	-50
7.C.1	137 x 140	1336	216.3	1115	274	-17
8.D.1	91 x 91	882	187.9	802	131	-9
11.D.1	102 - Dia	448	144.6	427	95	-5
14.D.3	76 - Dia	308	43.6	426	54	38
15.D.1	89 x 89	574	72.3	398	114	-31
17.D.1	89 x 89	955	195.7	946	72	-1
17.D.2	89 x 140	1891	551.6	1645	805	-13
23.D.1	86 x 86	184	108.6	175	61	-5
23.C.1	132 x 132	259	110.9	181	68	-30
26.D.1	89 x 89	168	56.9	161	35	-4
26.D.2	140 x 140	179	27.3	209	9	17
28.D.1	89 x 89	257.98	36.7	235	41	-9
32.D.1	94 x 94	981.07	308.4	789	101	-20

A – difference is computed relative to non-conditioned specimens

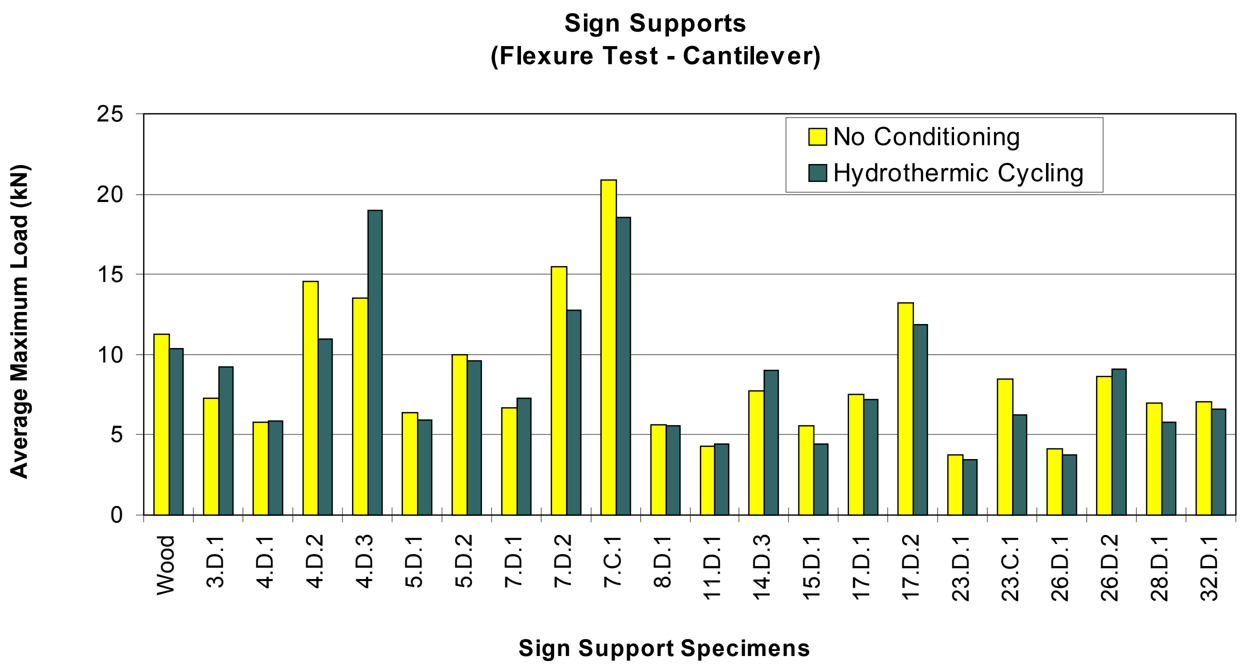

Figure 36. Effect of Hydrothermic Cycling Process on Average Maximum Load Capacity of Sign Support Specimens.

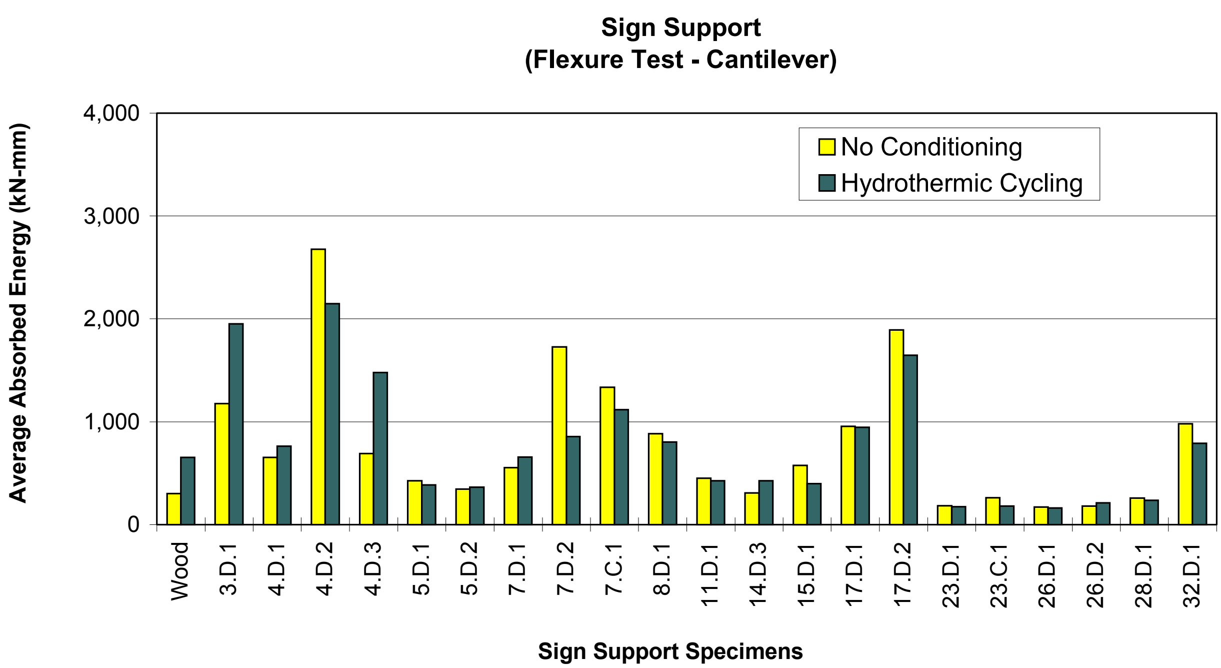

Figure 37. Effect of Hydrothermic Cycling Process on Average Energy Absorption of Sign Support Specimens.

5.2.3 Impact

Table 20 summarizes the results from impact tests conducted on sign supports. The table illustrating the results in greater detail is available from TTI. For each candidate, three representative samples were tested to obtain the average response. In Table 20, comparisons between recycled materials and conventional materials are given in terms of 10 ms average peak force and absorbed energy during impact. The 10 ms average peak force was computed from pendulum acceleration data. As with guardrail posts, the absorbed energy was calculated from the area under the material's average peak force-deflection curve. A sample calculation of absorbed energy is available from TTI.

As shown in Table 20, the 10 ms average force measured for all the candidate sign supports ranged from 22 kN (4.9 kips) for specimen 23.D.1 to 74.1 kN (16.7 kips) for specimen 4.D.3. For the conventional 102 mm H 102 mm (4 in H 4 in) wood sign support, the 10 ms average force was 36.3 kN (8.2 kips). Thus, as shown in Figure 38, the capacity of specimens 4.D.1, 4.D.2, 4.D.3, 5.D.2, 7.D.2, 7.C.1, 14.D.1, 14.D.3, and 23.C.1 is deemed promising when compared to baseline results. The performance of specimens 3.D.1, 7.D.1, 17.D.1, and 23.D.1 was also considered satisfactory. However, specimens 5.D.1 and 8.D.1 performed poorly when compared to other candidate sign supports.

The average energy dissipation of candidate sign supports is shown in Figure 39. The absorbed energy for specimens 3.D.1, 4.D.1, 4.D.2, 4.D.3, 5.D.2, 7.D.2, 7.C.1, 14.D.1, 14.D.3, and 23.C.1 showed promise. Energy absorption for specimens 5.D.1, 8.D.1, and 23.D.1 was lower than other candidate sign supports. It should be noted that the impact test was not performed on specimens 15.D.1, 26.D.1, 28.D.1, 32.D.1, 17.D.2, 11.D.1, and 26.D.2 due to unavailability of those specimens.

Table 20. Impact Test Results for Sign Support Specimens.

Specimen Code	Member Size (mm x mm)	10 ms Average Peak Force (kN)	Peak Force Difference[A] (%)	Dissipated Energy (kN-mm)	Dissipated Energy Difference[B] (%)
Wood	89 x 89	36.3	0	3,399	0
3.D.1	84 x 84	28.4	-22	3,114	-8
4.D.1	89 x 89	32.8	-10	3,283	-3
4.D.2	114 x 114	50.3	38	6,810	100
4.D.3	140 x 140	74.1	104	7,845	131
5.D.1	89 x 89	23.4	-36	2,250	-34
5.D.2	89 x 140	32.8	-10	3,027	-11
7.D.1	86 x 86	29.9	-18	2,949	-13
7.D.2	89 x 137	49.7	37	6,483	91
7.C.1	137 x 140	62.8	73	6,397	88
8.D.1	91 x 91	23.0	-37	2,344	-31
14.D.1	102 - Dia.	43.3	19	3,926	16
14.D.3	76 - Dia.	31.1	-14	2,986	-12
17.D.1	89 x 89	27.9	-23	2,988	-12
23.D.1	86 x 86	22.0	-40	2,094	-38
23.C.1	132 x 132	31.3	-14	2,859	-16

A – difference was calculated based on performance of round wood post (Wood-R)
B – calculation was made based on sample maximum-minimum values

As mentioned previously, the breakaway performance is an important characteristic that needs to be evaluated for any candidate sign support. Results of impact testing indicate frangibility is not an issue for any of the candidate sign supports as they tend to fracture readily when impacted. However, the fracture pattern varied substantially for the candidate sign supports. For example, some sign supports fractured at the fixed base level and flew ahead of the pendulum (specimens 7.D.1, 8.D.1, 4.D.3, 4.D.2, 4.D.1, 3.D.1, and 17.D.1). Specimens such as 23.D.1, 5.D.2, 5.D.1, 7.D.2, 7.C.1, and 23.C.1 fractured at multiple points (point of impact and the fixed base) and the pieces scattered during impact.

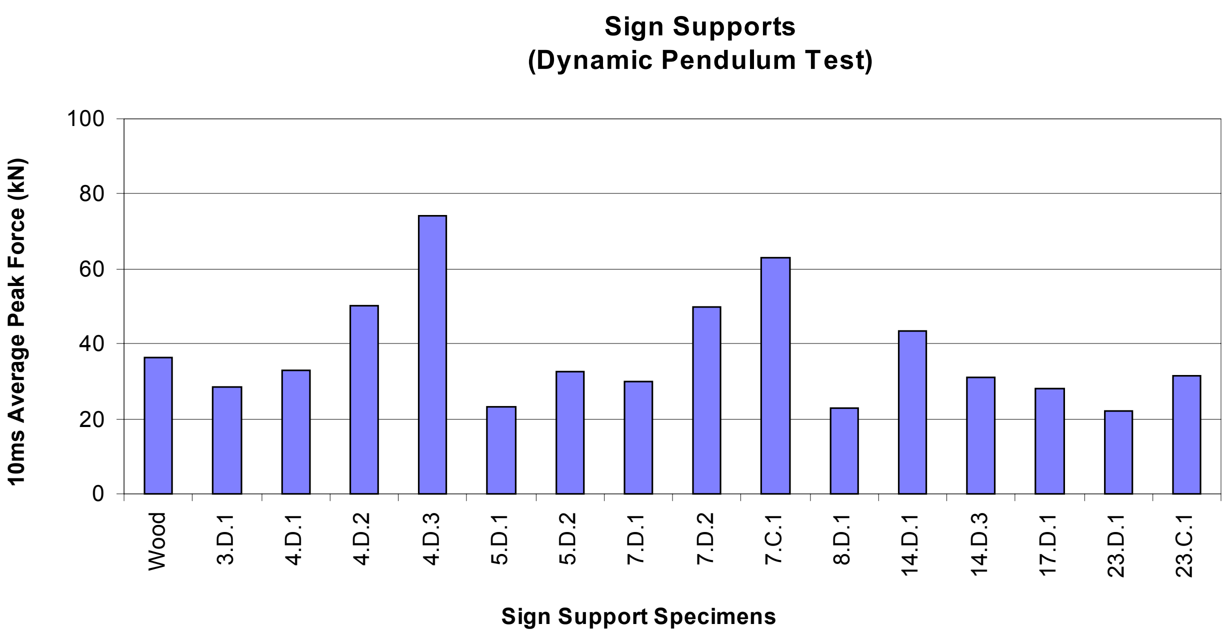

Figure 38. 10 ms Average Peak Force Exerted on Sign Support Specimens.

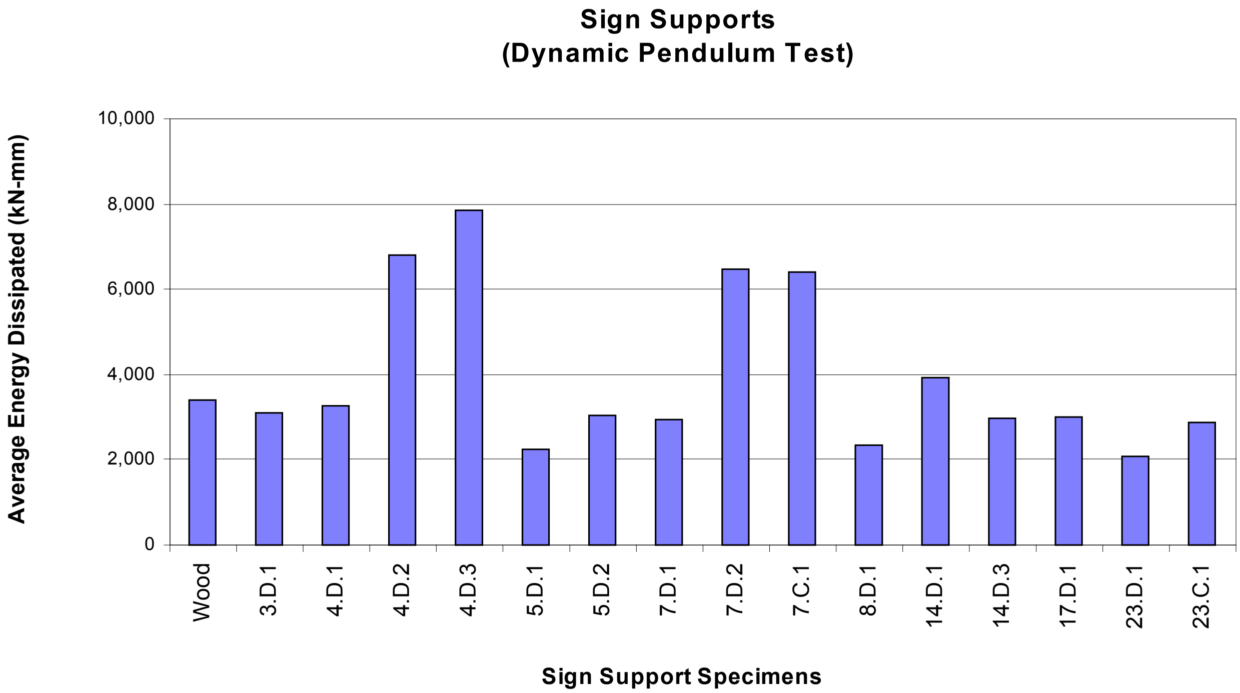

Figure 39. Energy Absorption of Sign Support Specimens.

5.2.4 Density

A summary of results on relative densities for candidate and baseline sign supports is given in Table 21. More detail is available from TTI. An 89 mm ς 89 mm ς 356 mm (3.5 in ς 3.5 in ς 14 in) No. 1 Douglas Fir wood specimen with a relative density of 450 kg/m^3 (28 lb/ft^3) was used as the baseline. For each candidate sign support, researchers tested three representative samples to obtain the average value. Unfortunately, the relative density of specimen 32.D.1 was not determined due to the specimen unavailability. Moreover, specimens 14.D.1 and 14.D.3 were not tested since the density of similar specimens was obtained previously (see Table 13). As shown in Table 21, the relative density of candidate sign support posts ranged from 617 kg/m^3 (38 lb/ft^3) for specimen 8.D.1 to 945 kg/m^3 (59 lb/ft^3) for specimen 5.D.2 making them almost 1.5 to 2.0 times as heavy as wood. These results are graphically represented in Figure 40.

Table 21. Relative Density Test Results for Sign Support Specimens.

Specimen Code	Specimen Size (mm x mm x mm)	Specific Gravity a / (a + w - b) (23/23 ^{0}C)	Relative Density[A] (kg / m^3)
Wood	89 x 89 x 356	0.45	450
3.D.1	84 x 84 x 356	0.90	896
4.D.1	89 x 89 x 356	0.83	827
4.D.2	114 x 114 x 356	0.80	799
4.D.3	140 x 140 x 356	0.81	806
5.D.1	89 x 89 x 356	0.91	910
5.D.2	89 x 140 x 356	0.95	946
7.D.1	86 x 86 x 356	0.92	817
7.D.2	89 x 137 x 356	0.63	624
7.C.1	137 x 140 x 356	0.72	715
8.D.1	91 x 91 x 356	0.62	617
11.D.1	102 - Dia.	0.89	889
15.D.1	89 x 89 x 356	0.73	725
17.D.1	89 x 89 x 356	0.73	731
17.D.2	89 x 140 x 356	0.65	646
23.D.1	86 x 86 x 356	0.90	895
23.C.1	132 x 132 x 356	0.83	824
26.D.1	89 x 89 x 356	0.77	763
26.D.2	140 x 140 x 356	0.74	737
28.D.1	89x 89 x 356	0.89	890

A–Relative Density = Specific Gravity * Density of Water
Density of Water = 997.6 kg/m^3

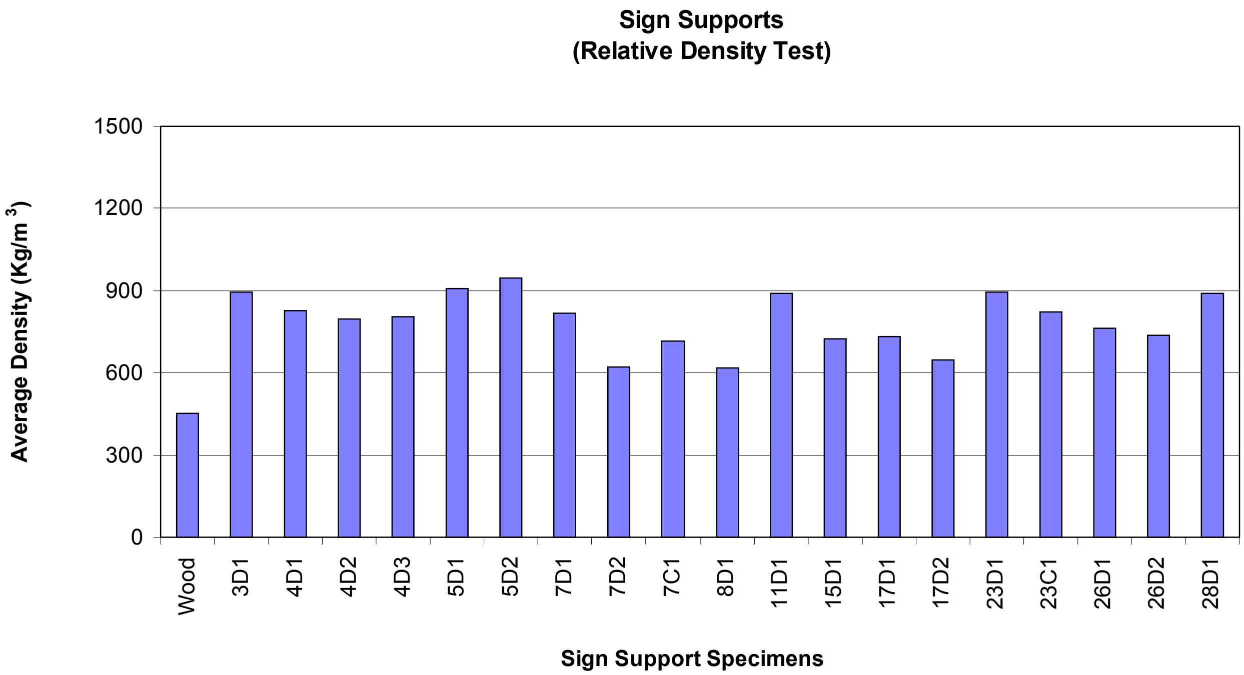

Figure 40. Relative Density Test Results for Sign Support Specimens.

5.2.5 Creep

Table 22 summarizes results obtained from creep tests on candidate sign supports. The table illustrating the results in greater detail is available from TTI. For each candidate support, three representative samples were tested to obtain the average response. The average results for both recycled materials and conventional materials are in terms of deflections and strains at initial, 240, and 1000 hours. The initial and 240-hour deflection measurements were based on the dial gage readings. The 1000-hour deflection was predicted from deflection data through the measured 240-hour test. As with the guardrail posts, the projected deflections were in good agreement with actual test data. Some of these curves along with the actual test data are available from TTI. The conventional 102 mm ς 102 mm (4 in ς 4 in) wood sign support was selected as the baseline for comparison purposes.

Comparisons for the average deflection measurements for the initial, 240-, and 1000-hour readings are shown in Figure 41. Some of the initial deflections (specimen 17.D.2) were seven times as large as those of wood. Averaged 240-hour deflections for all candidate sign supports ranged from 1 mm (0.04 in) for specimen 14.D.1 to 50 mm (1.99 in) for specimen 17.D.2. For the conventional wood sign support, the average 240-hour deflection was approximately 6 mm (0.25 in).

Calculated strain values for the same specimens are shown in Figure 42 for the initial, 240- and 1000-hour strains. The strain values for specimens 14.D.1, 14.D.3, 26.D.1, and 28.D.1 seemed promising when compared to baseline results. Additionally, the performance of specimens 3.D.1, 4.D.1, 5.D.1, 7.D.1, 11.D.1, 23.C.1, and 26.D.2 were considered satisfactory. However, when compared to the other sign supports, specimens 7.D.2, 15.D.1, 17.D.1, 17.D.2, 23.D.1, and 32.D.1 performed poorly in both 240-hour deflections and average strain for 240-and 1000-hour tests. It should be noted that the creep test was not performed on specimens 4.D.2, 4.D.3, 5.D.2, 7.C.1, and 8.D.1 due to specimen unavailability.

Table 22. Flexural Creep Test Results for Sign Support Specimens.

Specimen Code	Specimen Size (mm x mm)	Average Initial Deflection (mm)	Average Initial Percent Strain (%)	Average 240 hours Deflection (mm)	Average 240 hours Percent Strain (%)	Average 1000 hours Projected Deflection[A] (mm)	Average 1000 hours Projected Percent Strain[A] (%)
Wood	89 x 89	4.132	0.044	6.257	0.062	6.121	0.066
3.D.1	84 x 84	12.962	0.129	29.405	0.293	33.824	0.337
4.D.1	89 x 89	10.693	0.113	30.006	0.318	34.349	0.364
5.D.1	89 x 89	14.368	0.163	29.650	0.337	32.461	0.369
7.D.1	86 x 86	8.585	0.088	24.562	0.253	28.837	0.296
7.D.2	89 x 137	13.166	0.200	31.606	0.481	36.288	0.552
11.D.1	102 - Dia.	10.071	0.130	25.756	0.330	28.969	0.372
14.D.1	102 - Dia.	0.804	0.011	1.008	0.014	1.058	0.014
14.D.3	76 - Dia.	10.016	0.103	11.176	0.115	11.362	0.116
15.D.1	89 x 89	10.761	0.114	33.384	0.352	39.192	0.413
17.D.1	89 x 89	13.166	0.138	36.373	0.381	43.756	0.458
17.D.2	89 x 140	20.447	0.309	50.427	0.762	58.031	0.876
23.D.1	86 x 86	15.596	0.164	30.853	0.323	34.569	0.363
23.C.1	132 x 132	8.585	0.130	17.772	0.268	19.423	0.293
26.D.1	89 x 89	4.691	0.050	9.737	0.103	10.422	0.110
26.D.2	140 x 140	4.665	0.077	11.523	0.190	12.717	0.209
28.D.1	89 x 89	4.496	0.041	9.627	0.088	10.592	0.097
32.D.1	94 x 94	11.599	0.129	30.531	0.341	35.264	0.394

A – 240-hour data was used to obtain 1000-hour projected values

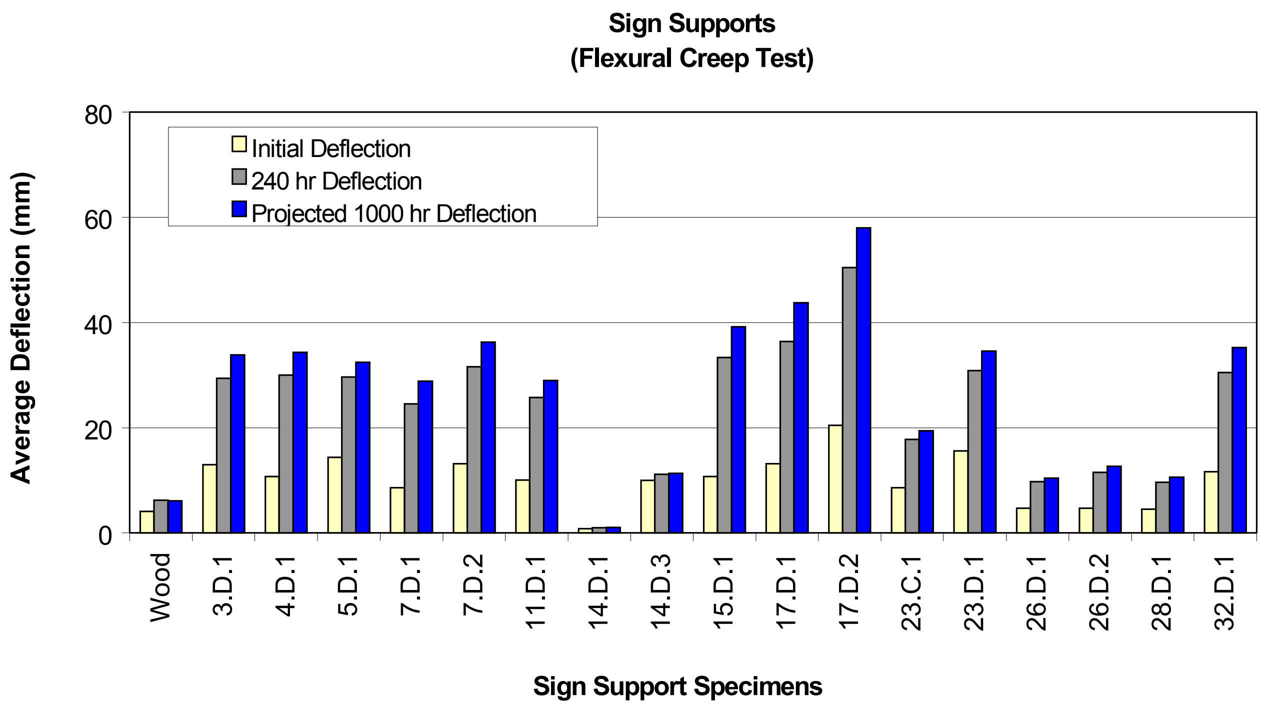

Figure 41. Average Flexural Creep Deflection Comparison for Sign Support Specimens.

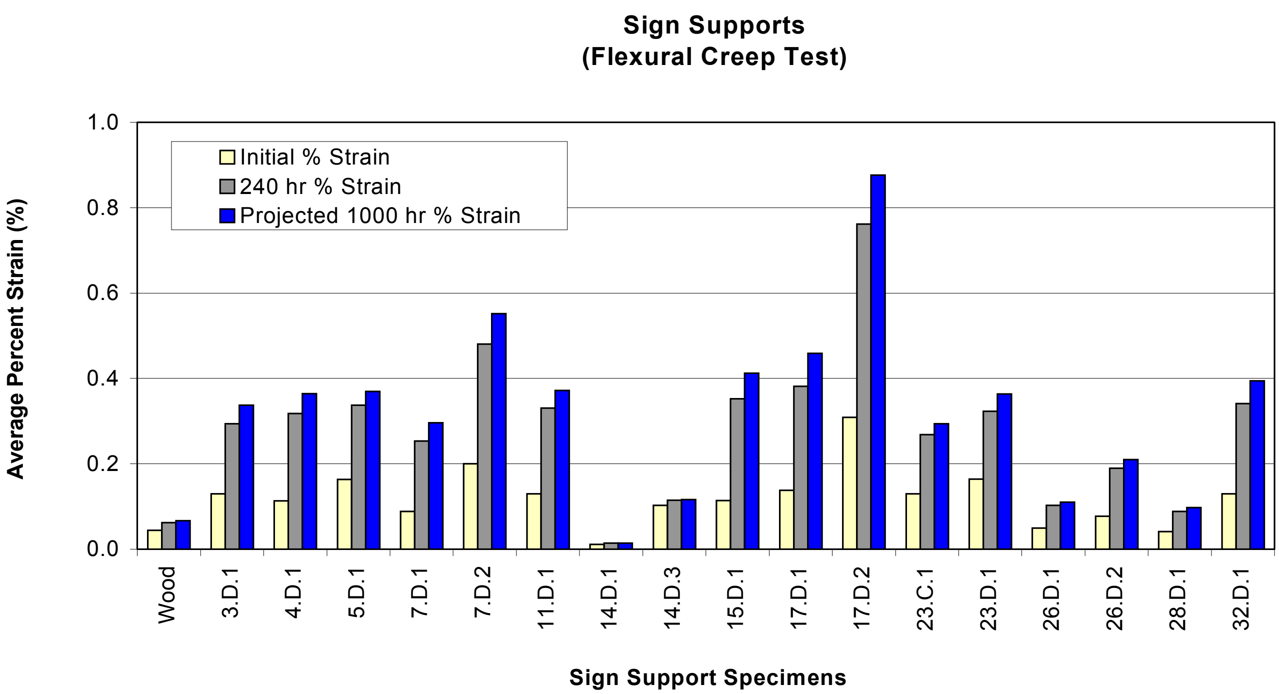

Figure 42. Percent Flexural Creep Strain Comparison for Sign Support Specimens.

5.2.6 Warpage

Table 23 summarizes the results obtained from warpage tests conducted on candidate sign supports. The table illustrating the results in greater detail is available from TTI. For each candidate, three representative samples were tested to obtain the average response. The maximum measured deflections in both axes is given for both recycled products and conventional materials in Table 23. Movement and warpage were identified by measurements taken on two adjacent sides of the posts for a period of six months. Post deflections were a result of uneven surface warming by the movement of the sun; all posts deformed back and forth during a day. Thus, researchers determined the total movement of a post by measuring the maximum deflections in each direction and adding the two values. The conventional 89 mm ς 89 mm (3.5 in ς 3.5 in) wood sign support was selected as the baseline for comparison purposes.

Graphical comparisons of total movement of the sign supports are shown in Figure 43. As shown from the figure, some recycled specimen warpage was smaller than that of wood. Total translations measured for all specimens ranged from 10 mm (0.39 in) for specimen 14.D.3 to 100 mm (3.94 in) for specimen 4.D.2. The maximum translation for the baseline wood post was 72 mm (2.83 in). Thus, as shown in Figure 43, total translation of specimens 3.D.1, 7.C.1, 14.D.1, 14.D.3, and 26.D.2 appeared promising when compared to baseline results. The performance of specimens 4.D.3, 5.D.1, 5.D.2, 7.D.1, 7.D.2, 8.D.1, 17.D.1, 23.C.1, 23.D.1, 26.D.1, and 28.D.1 were also considered satisfactory. Specimens 4.D.1, 4.D.2, 11.D.1, 15.D.1, and 17.D.2, however, performed poorly when compared to baseline and other candidate sign supports. The warpage test was not performed on specimen 32.D.1 due to the specimen unavailability. Sample data is shown in Table 39 and Figure 55 in Appendix B.

Warpage on recycled material supports was a result of thermal changes while warpage on the baseline wood support was due to moisture content changes. As mentioned previously, movement on the recycled material supports was documented over the course of any given day due to heating of various support faces by the sun. The bowing or warping of the baseline wood support occurred gradually over the course of the test. This is a common occurrence with wood supports. As wood dries, knots and nonuniform ring densities cause disproportionate shrinkage to occur. Therefore, lumber products are prone to warp when exposed to the elements for extended periods of time.

Table 23. Warpage Test Results for Sign Support Specimens.

Specimen Code	Specimen Size (mm x mm)	Maximum Deflections (mm)	
		East-West	North-South
Wood	89 x 89	72	59
3.D.1	84 x 84	36	35
4.D.1	89 x 89	86	70
4.D.2	114 x 114	100	57
4.D.3	140 x 140	64	49
5.D.1	89 x 89	40	33
5.D.2	89 x 140	46	39
7.D.1	86 x 86	48	33
7.D.2	89 x 137	49	49
7.C.1	137 x 140	36	34
8.D.1	91 x 91	67	55
11.D.1	102 - Dia.	83	71
14.D.1	102 - Dia.	23	21
14.D.3	76 - Dia.	22	10
15.D.1	89 x 89	78	52
17.D.1	89 x 89	64	45
17.D.2	89 x 140	84	49
23.D.1	86 x 86	45	45
23.C.1	132 x 132	47	39
26.D.1	89 x 89	52	38
26.D.2	140 x 140	19	14
28.D.1	89 x 89	79	21

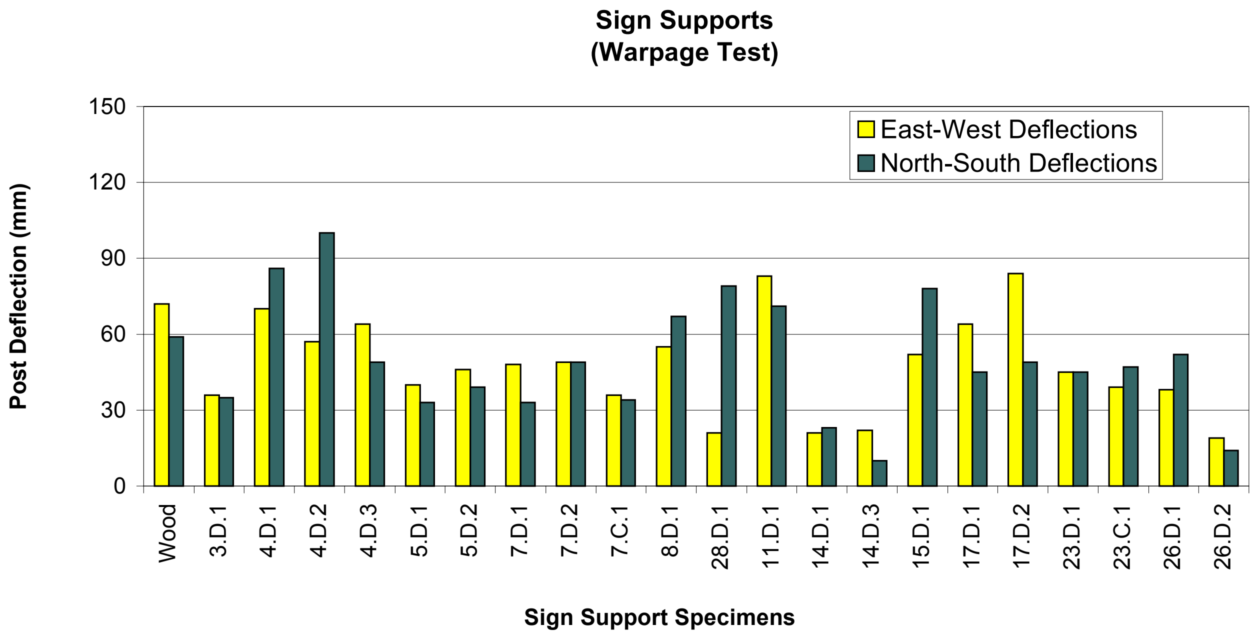

Figure 43. Warpage Test Results for Sign Support Specimens.

5.3 OFFSET BLOCKS

5.3.1 Compression

Table 24 summarizes the results from the compression test conducted on guardrail offset block candidates at hot (50 EC (122 EF)), cold (0 EC (32 EF)), and room temperature (23 EC (73 EF)). Representative load-deflection curves from these tests and the tables shown in greater detail are available from TTI. The percent changes were based on the difference in the maximum and minimum values and presented to demonstrate the effect of temperature on offset block behavior.

The area under the materials' load-deflection curve was used to compute absorbed energy. To provide a uniform evaluation criteria among offset blocks, the deflection was limited to 15 mm (or failure of the material). A sample calculation of energy absorption is also available from TTI. The conventional 152 mm ς 203 mm ς 356 mm (6 in ς 8 in ς 14 in) wood guardrail offset block was selected as the baseline for comparison purposes. In addition, the test result of conventional W150ς13.5 (W6ς9) structural steel guardrail offset block is also shown.

Most of the specimens failed by a combination of crushing and buckling as shown in Figure 44. For the specimens 17.B.1, 26.B.1, 3.B.1, and 3.B.2 containing large core regions, failures initiated at the intersection between the core and the shell region and propagated along the same boundary (see Figure 44). On the other hand, solid specimens 6.B.1 and 28.B.1 did not exhibit fracture, but rather, continued to deform plastically at or near the maximum load. For those members, the test was stopped when a deflection of 15 mm (0.6 in) was reached. Sample data is shown in Table 40 and Figure 56 in Appendix B.

The averaged loads measured for all recycled guardrail offset blocks ranged from 193 kN for 6.B.1 at 50 EC (122 EF) to 1174 kN for 3.B.2 at 0 EC (32 EF). The average maximum load for the baseline wood specimens was 340 kN, obtained during cold temperature test. It was determined that the temperature had a substantial effect on the load carrying capacity for the offset blocks. As shown in Table 24, all specimens underwent some strength loss as the temperature increased. For instance, the increase in temperature from 0 to 50 EC (32 to 122 EF) led to a maximum reduction of 83 percent in average load capacity for the specimen 6.B.1. However, all of the candidate guardrail offset blocks outperformed the baseline wood specimens in terms of both maximum load carrying capacity and energy dissipation at 0 and 23 EC (32 and 74 EF).

Table 24. Compression Test Results for Guardrail Offset Block Specimens.

Specimen Code	Member Size (mm x mm x mm)	Average Maximum Load (kN)				Average Deflection @ Maximum Load (mm)				Average Dissipated Energy (kN-mm)			
		0EC	23EC	50EC	% Change[A]	0EC	23EC	50EC	% Change[A]	0EC	23EC	50EC	% Change[A]
Wood	152 x 203 x 356	340	258	276	24	13	15	15	15	3,144	2,897	2,845	10
W6x9	102 x 152 x 356	498	452	341	32	4	4	3	25	463	474	325	31
3.B.1	127 x 178 x 356	604	359	225	63	14	15	15	7	5,413	2,894	1,923	64
3.B.2	178 x 178 x 356	1,174	706	424	64	15	15	15	0	10,950	6,215	3,794	65
6.B.1	152 x 203 x 356	1,135	406	193	83	15	15	15	0	10,907	3,567	1,700	84
17.B.1	152 x 203 x 356	565	393	215	62	15	15	15	0	4,029	2,493	1,484	63
26.B.1	152 x 203 x 356	567	706	289	49	10	15	15	50	3,807	6,215	2,896	53
28.B.1	152 x 203 x 356	668	718	394	41	15	15	15	0	6,279	6,087	3,483	45

A – percent change was calculated based on sample maximum- minimum values

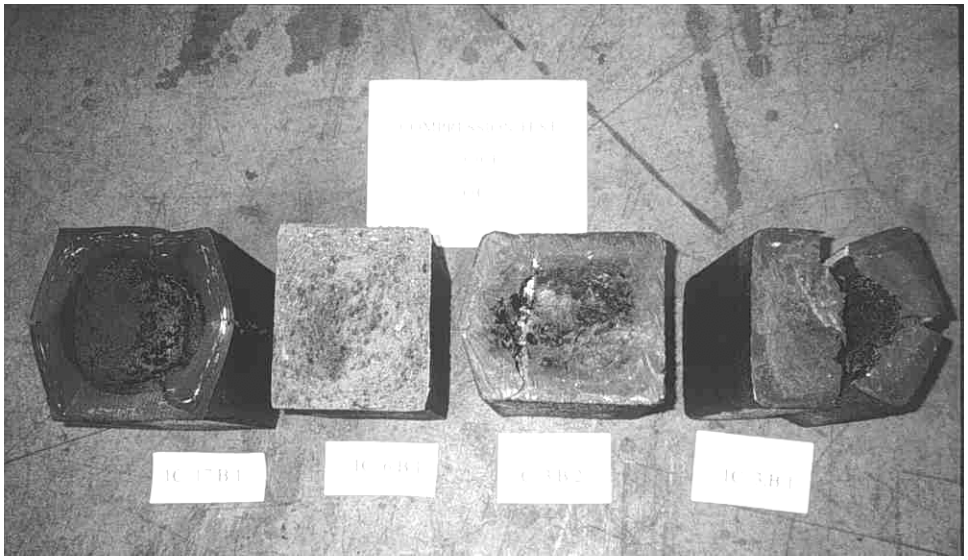

Figure 44. Observed Failure Mechanism for Guardrail Offset Blocks.

The relationship between the average maximum load carrying capacity and change in temperature for the candidate offset blocks is shown in Figure 45. As shown in Figure 46, a similar trend was observed for the calculation of the average energy absorption for the candidate offset blocks due to the strength deterioration that occurred in the specimens at high temperatures. It was also determined that the deformation capacity of specimens seriously decreased when the specimens were tested in lower temperatures.

In order to determine the average response for each candidate, five specimens were tested. The range of values observed in these tests provides some indication regarding the consistency and quality of the product. A summary table showing the core region and shell dimensions for offset block specimens is given in Table 25.

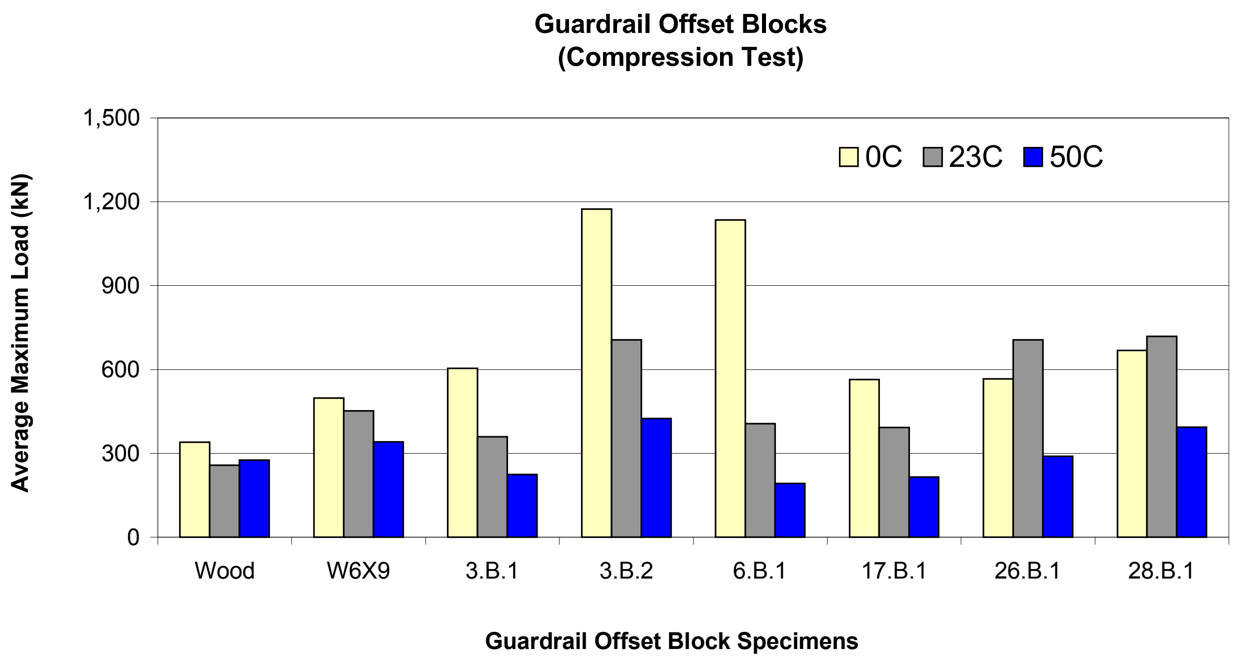

Figure 45. Average Maximum Load Comparison for Guardrail Offset Block Specimens.

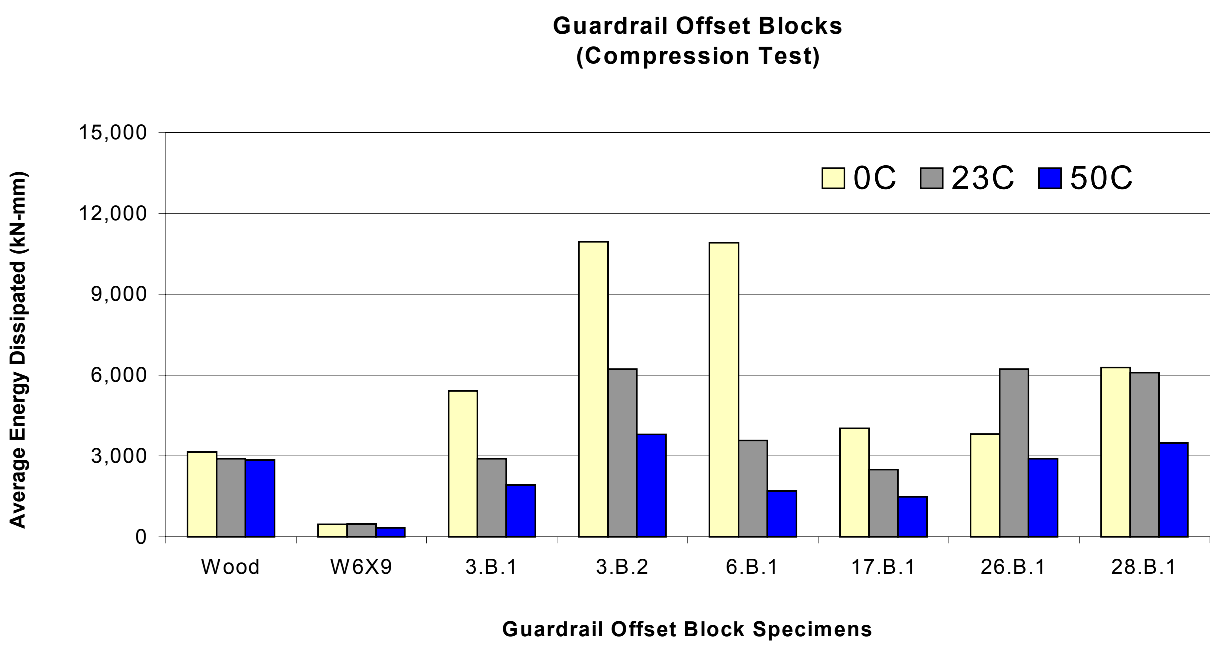

Figure 46. Average Energy Absorption Comparison for Guardrail Offset Block Specimens.

Table 25. Core Region - Shell Dimension Comparison for Guardrail Offset Block Specimens.

Specimen Code	Shape	Dimensions (mm)		Manufacturing Process
		Overall	Core	
Wood	Rectangular	152 x 203	0	Southern Yellow Pine
W6x9	W-shape	102 x 152	0	Structural Steel Shape
3.B.1	Rectangular	127 x 178	80 x 120	Molded
3.B.2	Square	178 x 178	120 x 120	Molded
6.B.1	Rectangular	152 x 203	0	Continuously Extruded
17.B.1	Rectangular	152 x 203	110 x 130	Extruded
26.B.1	Rectangular	152 x 203	110 x 140	Continuously Extruded
28.B.1	Rectangular	152 x 203	80 x 120	Molded

5.3.2 Hydrothermic Cycling

Researchers performed the hydrothermic cycling process in order to determine the change, if any, in the compressive strength of offset blocks when subjected to freeze/thaw cycles. For every specimen, five representative samples were tested. The range of values observed in these tests provides some indication regarding the consistency and quality of the product. A summary of the compression test results showing the performance of guardrail offset blocks before and after hydrothermic cycling process is given in Tables 26 and 27. In these tables, the average percent changes for both maximum load and absorbed energy are given based on the change between the unconditioned and conditioned specimen performances. The same results are also given in Figures 47 and 48 in the form of bar charts. Representative load-deflection curves for conditioned specimens and the tables illustrating the results in greater detail are available from TTI.

Although Figure 47 displays that the hydrothermic cycling process has a substantial impact on the load carrying capacity of most of the guardrail offset block specimens, the effect became minimal once the standard deviations were taken into account (see Table 26). From the strength standpoint, the hydrothermic cycling process has shown a positive effect for specimens 3.B.1, 6.B.1, and 17.B.1. This occurred due to the variance in the load carrying capacities of offset blocks and can be understood as no effect. For specimens 3.B.2 and 28.B.1, the change was 8 percent and 2 percent, respectively, showing the insignificant effect of hydrothermic cycling process on those specimens. However, the specimen 26.B.1 showed a substantial loss of 36 percent in the load carrying capacity when subjected to hydrothermic cycling process. This occurred mainly because of the existing fiberglass in its composition. It should be mentioned that in terms of strength, all candidate guardrail offset block specimens outperformed the baseline wood specimens after subjected to hydrothermic cycling process.

The average energy dissipation of candidate guardrail offset blocks is shown in Figure 48. As shown in the figure, the absorbed energy and the load carrying capacity charts look almost identical. Moreover, the percent changes for the average absorbed energy before and after hydrothermic cycling process were observed to be following the similar trend as average load capacity.

Table 26. Effect of Hydrothermic Cycling Process on Load Carrying Capacity of Guardrail Offset Block Specimens.

Specimen Code	Member Size (mm)	No Conditioning		Hydrothermic Cycling		Change[A] (%)
		Average Maximum Load (kN)	Standard Deviation	Average Maximum Load (kN)	Standard Deviation	
Wood	152 x 203 x 356	258	33.37	220	66.97	15
3.B.1	127 x 178 x 356	359	105.98	546	149.75	-52
3.B.2	178 x 178 x 356	706	63.07	646	65.70	8
6.B.1	152 x 203 x 356	406	12.26	448	12.29	-10
17.B.1	152 x 203 x 356	393	22.73	467	53.52	-19
26.B.1	152 x 203 x 356	706	73.44	453	68.86	36
28.B.1	152 x 203 x 356	718	121.85	701	84.89	2

A – difference is computed relative to non-conditioned specimens

Table 27. Effect of Hydrothermic Cycling on Energy Absorption of Guardrail Offset Block Specimens.

Specimen Code	Member Size (mm)	No Conditioning		Hydrothermic Cycling		Change[A] (%)
		Average Absorbed Energy (kN-mm)	Standard Deviation	Average Absorbed Energy (kN-mm)	Standard Deviation	
Wood	152 x 203 x 356	2,897	300	2,342	838	19
3.B.1	127 x 178 x 356	2,894	1,176	4,782	1,346	-65
3.B.2	178 x 178 x 356	6,215	877	5,391	627	13
6.B.1	152 x 203 x 356	3,567	161	3,752	166	-5
17.B.1	152 x 203 x 356	2,493	208	3,087	447	-24
26.B.1	152 x 203 x 356	6,215	799	4,523	876	27
28.B.1	152 x 203 x 356	6,087	1,242	6,050	811	1

A – difference is computed relative to non-conditioned specimens

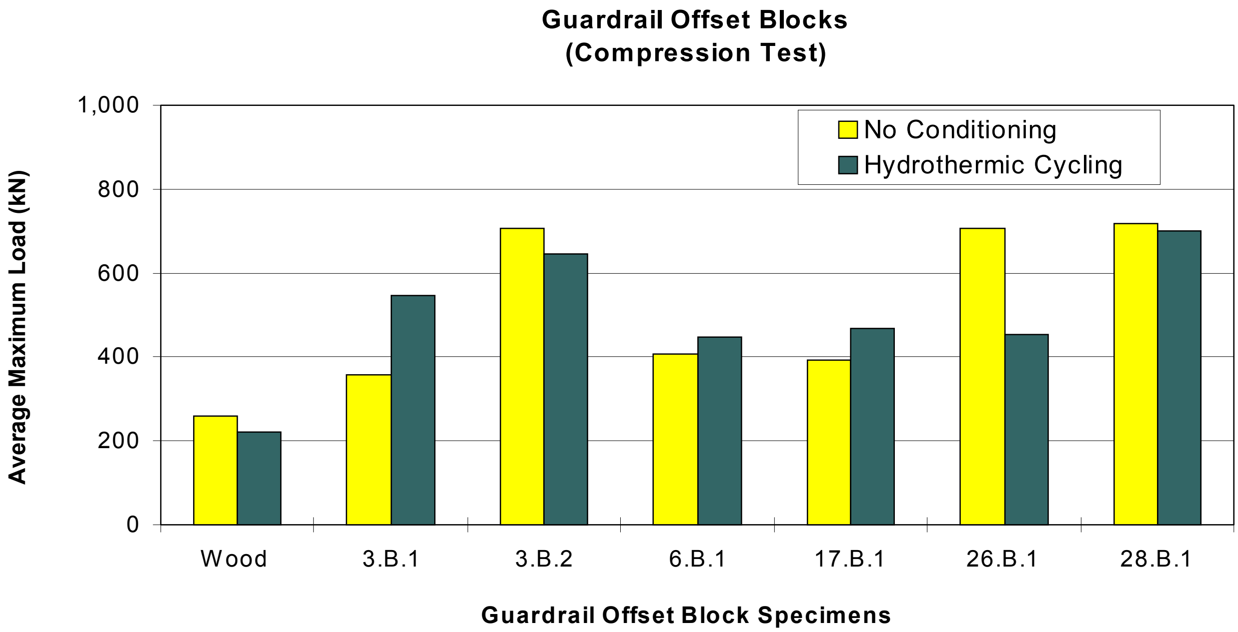

Figure 47. Effect of Hydrothermic Cycling Process on Average Maximum Load Capacity of Guardrail Offset Block Specimens.

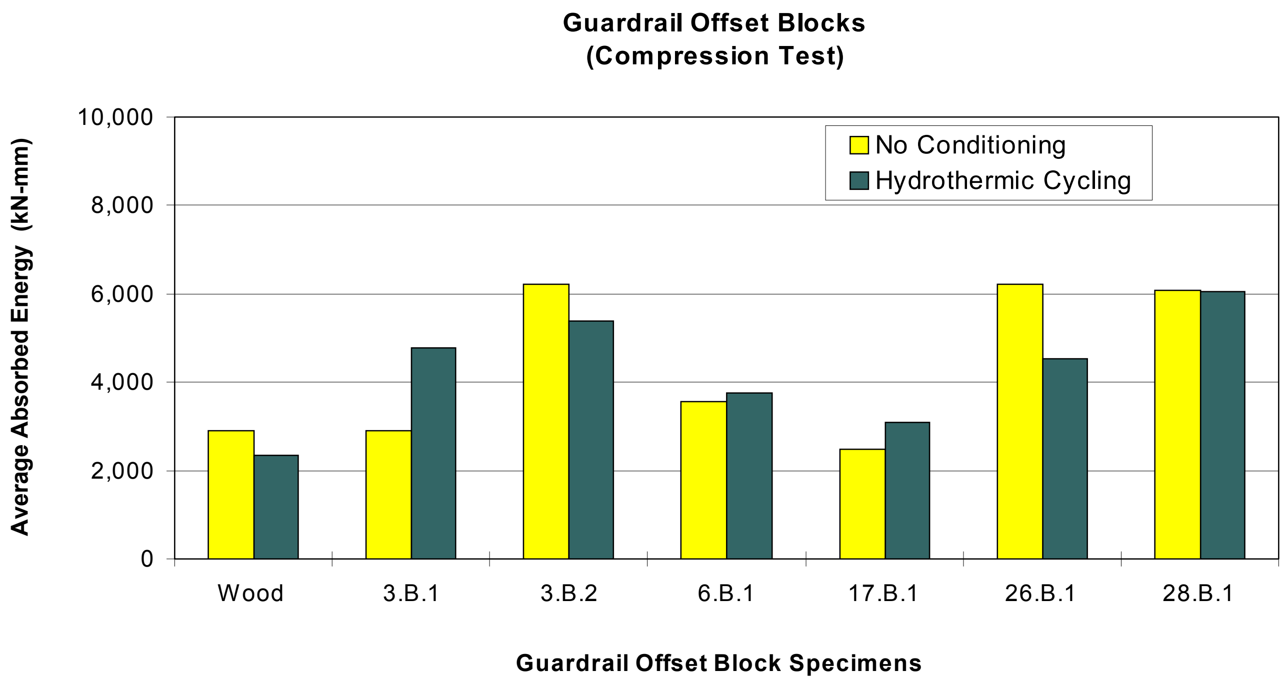

Figure 48. Effect of Hydrothermic Cycling Process on Average Energy Absorption of Guardrail Offset Block Specimens.

5.3.3 Density

Table 28 summarizes the test results showing the relative densities for the guardrail offset block candidates. The table showing the relative densities in greater detail is available from TTI. In Table 28, the specific gravity along with the relative density results for all the candidate guardrail offset blocks are shown, and these results are compared with baseline results. A 152 mm ς 203 mm ς 356 mm (6 in ς 8 in ς 14 in) No.1 Douglas Fir type wood specimen was used to represent the baseline performance. The relative density for wood was 450 kg/m^3 (28 lb/ft^3). In Figure 49, the relative density results are presented graphically. As shown in Figure 49, the relative density of candidate offset blocks ranges from 681 kg/m^3 (42.5 lb/ft^3) for specimen 17.B.1 to 1164 kg/m^3 (72.7 lb/ft^3) for specimen 6.B.1 making them approximately two to three times more dense than wood counterparts.

Table 28. Relative Density Test Results for Guardrail Offset Block Specimens.

Specimen Code	Specimen Size (mm x mm x mm)	Specific Gravity a / (a + w ! b) (23/23 EC)	Relative Density[A] (kg/m^3)
Wood	152 x 203 x 356	0.45	450
3.B.1	127 x 178 x 356	0.75	753
3.B.2	178 x 178 x 356	0.80	802
6.B.1	152 x 203 x 356	1.17	1164
17.B.1	152 x 203 x 356	0.68	681
26.B.1	152 x 203 x 356	0.75	749
28.B.1	152 x 203 x 356	0.70	700

A–Relative Density = Specific Gravity * Density of Water
Density of Water = 997.6 kg/m^3

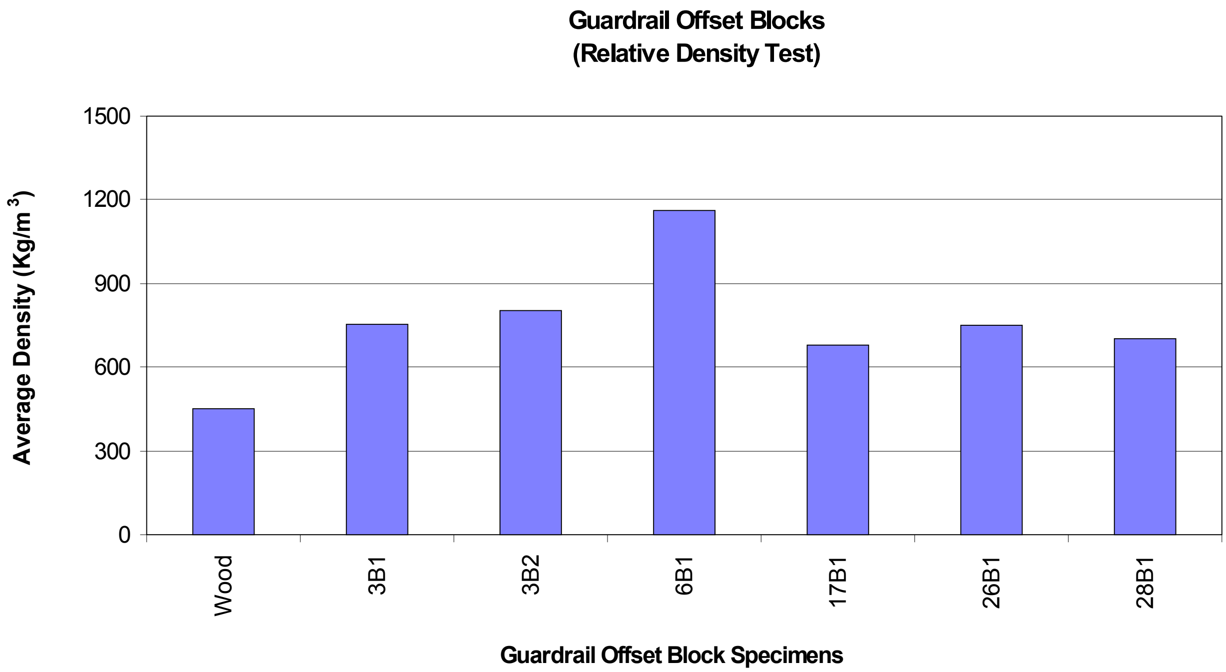

Figure 49. Relative Density Comparison for Guardrail Offset Block Specimens.

CHAPTER VI - PRODUCT RANKINGS

Numerous products have been subjected to a number of tests to determine mechanical properties and response to various environmental concerns. As indicated in Chapter II, the primary focus of applications has been as guardrail posts, sign supports, and guardrail blocks. Environmental concerns are minimal with all tested specimens. Water absorption was also minimal with most specimens; therefore, freeze/thaw concerns are negligible. Two facets of product performance must be considered:

- Does the product have good utility? Will the product perform the task in a fashion comparable to existing products at a reasonable price?
- Is the product safe? Does the product fracture or displace in a predictable, safe fashion?

The following table, Table 29, was developed for the ranking of the recycled products. Not all products were subjected to all tests when the criteria were deemed not applicable to specific applications.

Testing has indicated that many of the products will perform adequately as offset blocks since the material must withstand only compressive loads. Subsequent to this research project, a number of offset blocks manufactured from recycled materials have been tested by the private sector and accepted by FHWA for use on the National Highway System. Products evaluated by the above ranking procedure are listed in Table 30.

Many material properties affect the performance of guardrail posts and sign supports. The advisory panel has reviewed summaries on all products tested in this phase of the project. Products showing the most promise for successful crash tests as sign supports and guardrail posts have been selected.

Product 17.D.1 was the first product selected for testing as a temporary single sign support. It is an extruded product comprised of recycled high density polyethylene plastics. The post measured 90 mm ς 90 mm (3.5 in ς 3.5 in) cross section. Researchers selected product 3.D.1 as the second product to be tested as a temporary sign support. It is a molded 86 mm ς 86 mm ς 3658 mm (3.4 in ς 3.4 in ς 144 in) post composed of a

Table 29. Grading System Used to Rank Products.

Rating	Flexure Test		Hydrothermic Cycling		Pendulum Test		Warpage
	Load	Energy	Load % Change	Energy % Change	Load	Energy	
All Samples							
Poor (0)	x < -40%	x < -25%	x < -20%	x < -20%	x < -30%	x < -30%	x > 2.5-in
Fair (1)	-40% < x < -10%	-25% < x < 100%	-20% < x < -10%	-20% < x < -10%	-30% < x < -15%	-30% < x < -15%	1.5-in < x < 2.5-in
Good (2)	x > -10%	x > 100%	x > -10%	x > -10%	x > -15%	x > -15%	x < 1.5-in

Rating	Creep	3-pt Bend
		Load
Poor (0)	x > 1.2-in	x > 60%
Fair (1)	0.5-in< x <1.2 in	40% < x < 60%
Good (2)	x < 0.5-in	x < 40%

Rating	Compression Test		Hydrothermic Cycling		Temperature Sensitivity
	Load	Energy	Load % Change	Energy % Change	Load
Poor (0)	x < -40%	x < -25%	x < -20%	x < -20%	x > 60%
Fair (1)	-40% < x < -10%	-25% < x < 100%	-20% < x < -10%	-20% < x < -10%	40% < x < 60%
Good (2)	x > -10%	x > 100%	x > -10%	x > -10%	x < 40%

Table 30. Guardrail Blockout Selection Rankings.

Specimen	Compression Test		Hydrothermic Cycling		Temperature Sensitivity	Average	Rank
	Load	Energy	Load % Change	Energy % Change	Load	Rating	
3.B.1	2	1	2	2	0	1.400	2
3.B.2	2	2	2	1	0	1.400	2
6.B.1	2	1	2	2	0	1.400	2
17.B.1	2	1	2	2	0	1.400	2
26.B.1	2	2	0	0	1	1.000	3
28.B.1	2	2	2	2	1	1.800	1

blend of polyethylene plastics. Product 17.D.2 was selected as the last product to be tested as a temporary single sign support. This product is again an extruded post manufactured with recycled high density polyethylene and has a slightly larger cross section at 90 mm ς 140 mm (3.4 in ς 5.5 in). Rankings of the recycled sign supports tested under this phase of the project are listed in Table 31. Two separate rankings are provided. The first ranking is based on the average rating received by a product for all tests conducted on that product. However, several of the sign support candidates were received after the completion of the dynamic pendulum testing. Since many of the products received relatively high ratings in the pendulum testing, a second ranking is provided that excludes the pendulum testing so as not to generate bias against those not tested.

Allowable sign areas were computed for the various recycled sign support candidates based on the results of the cantilever load tests. The values obtained for sign aspect ratios of 1:2 and 1:1 are shown in Tables 32 and 33, respectively. The recycled products that could not accommodate a minimum sign area of (9 ft^2) were eliminated from further consideration.

There were limited products available for use as guardrail posts. Therefore, a process of elimination was used to arrive at a suitable product for full-scale testing. A number of products were tested as cantilevered section. The top performers from these tests were then subjected to subsequent tests until a single product was determined to show the most promise for a successful full-scale crash test. Product 3.C.3 was selected as the product with the most desirable characteristics for use as guardrail post and offset block based on test performance, cost, and availability. This molded polyethylene post measured 150 mm ς 200 mm (6 in ς 8 in) in cross section and 1829 mm (6 ft) in length. The offset blocks were manufactured with the same material and cross section, and the length were 356 mm (14 in).

Table 31. Sign Support Selection Rankings.

Specimen	Flexure Test		Hydrothermic Cycling		Pendulum Test		Warpage	Creep	3-pt Bend	Average	Rank	Rank
	Load	Energy	Load % Change	Energy % Change	Load	Energy			Load	Rating		Without Pendulum
4-in x 4-in												
3.D.1	1	2	2	2	1	2	2	1	0	1.444	1	1
4.D.1	0	2	2	2	2	2	0	1	1	1.333	2	3
7.D.1	0	1	2	2	1	2	1	1	0	1.111	4	4
8.D.1	0	2	2	2	0	0	1	NA	1	1.000	5	2
15.D.1	0	1	0	0	NA	NA	0	0	0	0.143	7	6
17.D.1	1	2	2	2	1	2	1	0	0	1.222	3	3
23.D.1	0	0	2	2	1	0	1	0	1	0.778	6	5
26.D.1	0	0	2	2	NA	NA	1	1	1	1.000	5	4
28.D.1	1	1	1	1	NA	NA	1	1	1	1.000	5	4
32.D.1	1	2	2	1	NA	NA	NA	0	0	1.000	5	4

Table 32. Allowable Sign Area (1:2 Aspect Ratio).

Manufacturer Code	Manufacturer Name	Member Size (in)	Average Maximum Load (lbs)	Max. Load Difference (%)	Allowable Moment (ft-lbs)	Calculated Moment (ft-lb)	Allowable Sign Area A (ft2)
Wood	Wood	3.5 × 3.5	2,254	0%	2,629	2,620	18
3.D.1	Alket Industries	3.3 × 3.3	1,386	-39%	1,617	1,613	12
4.D.1	Bedford Industries, Inc.	3.5 × 3.5	1,237	-45%	1,443	1,440	11
4.D.2	Bedford Industries, Inc.	4.5 × 4.5	3,155	40%	3,680	3,674	25
4.D.3	Bedford Industries, Inc.	5.5 × 5.5	2,857	27%	3,333	3,329	23
5.D.1	BTW Industries	3.5 × 3.5	1,390	-38%	1,622	1,620	12
5.D.2	BTW Industries	3.5 × 5.5	2,030	-10%	2,369	2,368	17
7.C.1	Duratech	5.4 × 5.5	4,472	98%	5,217	5,207	33
7.D.1	Duratech	3.4 × 3.4	1,406	-38%	1,641	1,635	12
7.D.2	Duratech	3.5 × 5.4	2,902	29%	3,386	3,375	23
8.D.1	Eaglebrook	3.6 × 3.6	1,219	-46%	1,423	1,419	11
11.D.1	Chicagoland Enviromint Corp.	4 - Dia.	882	-61%	1,029	1,028	8
14.D.1	Lancaster Composite	4 - Dia.	4,522	101%	5,275	5,268	33
14.D.3	Lancaster Composite	3 - Dia.	2,143	-5%	2,500	2,492	18
15.D.1	Metro Plastics	3.5 × 3.5	1,200	-47%	1,400	1,398	11
17.D.1	N.E.W. Plastics Corp.	3.5 × 3.5	1,608	-29%	1,876	1,870	14
17.D.2	N.E.W. Plastics Corp.	3.5 × 5.5	3,126	39%	3,647	3,637	24
23.C.1	Recycled Plastics Man	5.2 × 5.2	1,741	-23%	2,031	2,028	15
23.D.1	Recycled Plastics Man	3.4 × 3.4	686	-70%	800	799	6
26.D.1	Trimax	3.5 × 3.5	842	-63%	982	972	8
26.D.2	Trimax	5.5 × 5.5	2,382	6%	2,779	2,772	19
28.D.1	Earth Care	3.5 × 3.5	1,506	-33%	1,757	1,750	13
32.D.1	Syntal	3.7 × 3.7	1,487	-34%	1,735	1,734	13

A–assuming aspect ratio (length : width) of 1:2

Table 33. Computation for Allowable Sign Area (1:1 Ratio).

Manufacturer Code	Manufacturer Name	Member Size (in)	Average Maximum Load (lbs)	Max. Load Difference (%)	Allowable Moment (ft-lbs)	Calculated Moment (ft-lb)	Allowable Sign Area A (ft2)
Wood	Wood	3.5 × 3.5	2,254	0%	2,629	2,619	21
3.D.1	Alket Industries	3.3 × 3.3	1,386	-39%	1,617	1,609	14
4.D.1	Bedford Industries, Inc.	3.5 × 3.5	1,237	-45%	1,443	1,441	12
4.D.2	Bedford Industries, Inc.	4.5 × 4.5	3,155	40%	3,680	3,675	28
4.D.3	Bedford Industries, Inc.	5.5 × 5.5	2,857	27%	3,333	3,324	26
5.D.1	BTW Industries	3.5 × 3.5	1,390	-38%	1,622	1,619	14
5.D.2	BTW Industries	3.5 × 5.5	2,030	-10%	2,369	2,357	19
7.C.1	Duratech	5.4 × 5.5	4,472	98%	5,217	5,199	38
7.D.1	Duratech	3.4 × 3.4	1,406	-38%	1,641	1,638	14
7.D.2	Duratech	3.5 × 5.4	2,902	29%	3,386	3,383	26
8.D.1	Eaglebrook	3.6 × 3.6	1,219	-46%	1,423	1,423	12
11.D.1	Chicagoland Enviromint Corp.	4 - Dia.	882	-61%	1,029	1,028	9
14.D.1	Lancaster Composite	4 - Dia.	4,522	101%	5,275	5,257	39
14.D.3	Lancaster Composite	3 - Dia.	2,143	-5%	2,500	2,492	20
15.D.1	Metro Plastics	3.5 × 3.5	1,200	-47%	1,400	1,396	12
17.D.1	N.E.W. Plastics Corp.	3.5 × 3.5	1,608	-29%	1,876	1,871	16
17.D.2	N.E.W. Plastics Corp.	3.5 × 5.5	3,126	39%	3,647	3,643	28
23.C.1	Recycled Plastics Man	5.2 × 5.2	1,741	-23%	2,031	2,022	17
23.D.1	Recycled Plastics Man	3.4 × 3.4	686	-70%	800	799	7
26.D.1	Trimax	3.5 × 3.5	842	-63%	982	977	9
26.D.2	Trimax	5.5 × 5.5	2,382	6%	2,779	2,776	22
28.D.1	Earth Care	3.5 × 3.5	1,506	-33%	1,757	1,747	15
32.D.1	Syntal	3.7 × 3.7	1,487	-34%	1,735	1,727	14

A–assuming aspect ratio (length : width) of 1:1

CHAPTER VII - CONCLUSIONS

This report summarizes the second phase of a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. In the first phase of this project, information regarding recycled material manufacturers and their products was acquired through an extensive literature review and survey of research organizations, various state and federal transportation agencies, professional and trade societies, and manufacturers. The information received was categorized into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having possibility to use in such applications. Thus, in the second phase of this project, those products lacking the desired data were evaluated to make a conclusive decision regarding their suitability for implementation.

Seventeen different recycled material manufacturers having one or more products with potential application in the areas of interest agreed to collaborate with TTI on this study. Full-scale specimens were obtained in order to account for size effects and the non-homogeneous nature of the materials. The products consisted of various different compositions and shapes including the following:

- plastic and wood fiber mixture
- plastic and glass fiber mixture
- commingled plastics
- 100% HDPE
- HDPE – LDPE mixture
- steel reinforced plastics
- concrete filled fiberglass tubes
- solid and hollow shapes

Received materials and products were sorted according to their potential use for roadside safety applications. After the classification, the testing focused primarily on the applications of guardrail posts, guardrail offset blocks, and sign supports, which were all identified in Phase I as areas with high potential that lacked suitable recycled alternatives.

To make a conclusive decision regarding the suitability for implementation for these received recycled materials and products, Phase II of this project involved a series of laboratory and dynamic tests. Basic physical and mechanical properties of the recycled products were determined through static laboratory tests such as flexure, compression, creep, and density. Response to environmental variables such as temperature, moisture, and freeze/thaw were investigated through exposure tests. The dynamic behavior of the materials was examined using pendulum tests. A unique test matrix was established for each application area. Currently used nationally recognized roadside safety applications were also tested in order to provide baseline performances. The suitability of materials was determined prior to the running of any dynamic tests to assure that the products would meet basic service requirements. Based on the results obtained from the recycled materials and products, some general conclusions can be made as follows:

(1) For most of the recycled products, the variability in test results was small. This indicates consistency in material composition for a given manufacturer. Commingled products were an exception. These products tended to be relatively weak and exhibit more variation in testing than those products comprised primarily of one type of plastic. As with other products, some type of sampling, testing, and inspection process should be established for any engineered recycled products to help ensure consistency in material composition and product performance.

(2) The products showed a wide range in behavior due to the different material compositions. It was determined that some of the mechanical properties of the recycled materials and products did not compare favorably to the conventional wood or steel baseline materials; stiffnesses were much lower and the tendency to creep was much greater.

(3) Although a number of products appear to offer potential for satisfactory performance for different roadside safety applications, the laboratory tests alone are not sufficient to draw definitive conclusions regarding their acceptability. Nonetheless, the results have been used to develop a prioritized ranking of products for each application investigated. These rankings will be used to guide

the product selection process for the limited crash test program conducted under Phase III of the project.

(4) Temperature has a significant effect on the mechanical properties of recycled materials. It was determined for most plastics, the load capacity, energy dissipation and the initial stiffness are inversely proportional with the temperature. This behavior was not observed for materials containing concrete core. Such variation in material behavior with temperature is generally not desirable when a product will be exposed to a significant operating range of temperatures. However, since plastics are typically subject to such variations, the goal is to identify products that will maintain acceptable performance within the range of temperatures anticipated in the field. This is difficult to do through testing since many types of tests outside the laboratory cannot be readily conducted at different temperature extremes. In such situations, the in-service performance of the product should be monitored to help identify any potential problems. This is a prudent course of action for any safety related project regardless of material composition.

(5) Virtually none of the materials were adversely affected by the hydrothermic cycling process. This was not unexpected since most of the recycled products investigated were comprised of various types of plastic that are closed cell materials, which are not generally susceptible to moisture absorption.

(6) The energy absorption capacity of the guardrail posts specimens tended to increase when shallower embedment depths were used. Because the soil resistance varies with the square of the embedment depth, the shallower embedment depths can delay or eliminate failure of the post. Consequently, the additional post rotation results in additional energy absorption. This can be beneficial in terms of guardrail performance. Early failure of a guardrail post can lead to vehicle pocketing, which can increase snagging on downstream posts and increase tensile stresses in the guardrail element. More testing is needed to establish more conclusive results regarding optimal post embedment depths.

CHAPTER VIII - RECOMMENDATIONS

The performance of recycled materials and products is different than the traditional timber or steel products currently used by TxDOT. Therefore, some of the suggested requirements in the draft specifications currently used by TxDOT may not be appropriate for recycled materials and products, and adjustments are needed, especially for sign supports and guardrail posts. Specifically, the modulus of elasticity (stiffness) is typically lower for most recycled plastics when compared to the wood counterparts. It is further anticipated that recycled products may creep under sustained loads.

It was recommended the most promising applications should be crash tested to complete development of standards and specifications for recycled materials and products. Applications recommended for crash testing were (1) guardrail posts, (2) sign supports, and (3) offset blocks. After completion of the crash testing program, the performance specifications will be developed providing an adequate level of safety and security for applications of recycled materials and products as roadside safety devices.

APPENDIX A - BIBLIOGRAPHY

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APPENDIX B - SAMPLE TEST DATA

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature.

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
0	0.1686	0	0.16855		0	0.7497	
0.05	0.1735	0.02	0.1735	0.0034205	0.508	0.7717	0.386445
0.1	0.1809	0.04	0.18094	0.0069649	1.016	0.8048	0.786888
0.15	0.1859	0.06	0.1859	0.0106333	1.524	0.8269	1.201341
0.2	0.2838	0.08	0.2838	0.0153303	2.032	1.2623	1.732005
0.25	0.4065	0.1	0.4065	0.0222333	2.54	1.8081	2.511900
0.3	0.5069	0.12	0.50688	0.0313671	3.048	2.2546	3.543829
0.35	0.6097	0.14	0.60974	0.0425333	3.556	2.7121	4.805378
0.4	0.7052	0.16	0.70517	0.0556824	4.064	3.1366	6.290953
0.45	0.7758	0.18	0.77581	0.0704922	4.572	3.4508	7.964152
0.5	0.87	0.2	0.87	0.0869503	5.08	3.8698	9.823575
0.55	0.9568	0.22	0.95675	0.1052178	5.588	4.2556	11.887422
0.6	1.0249	0.24	1.02492	0.1250345	6.096	4.5588	14.126297
0.65	1.0943	0.26	1.09432	0.1462269	6.604	4.8675	16.520598
0.7	1.1489	0.28	1.14885	0.1686586	7.112	5.1101	19.054913
0.75	1.2009	0.3	1.2009	0.1921561	7.62	5.3416	21.709642
0.8	1.2765	0.32	1.2765	0.2169301	8.128	5.6779	24.508589
0.85	1.3149	0.34	1.31492	0.2428443	8.636	5.8488	27.436354
0.9	1.3558	0.36	1.35581	0.2695516	9.144	6.0306	30.453724
0.95	1.4079	0.38	1.40787	0.2971884	9.652	6.2622	33.576107
1	1.4252	0.4	1.42522	0.3255193	10.16	6.3394	36.776910
1.05	1.4562	0.42	1.4562	0.3543335	10.668	6.4772	40.032315
1.1	1.5132	0.44	1.51321	0.3840276	11.176	6.7308	43.387131
1.15	1.5702	0.46	1.57022	0.4148619	11.684	6.9843	46.870766
1.2	1.6185	0.48	1.61855	0.4467496	12.192	7.1993	50.473412
1.25	1.6768	0.5	1.6768	0.4797031	12.7	7.4584	54.196472
1.3	1.7227	0.52	1.72265	0.5136976	13.208	7.6623	58.037144
1.35	1.7846	0.54	1.78462	0.5487703	13.716	7.938	61.999629
1.4	1.8193	0.56	1.81932	0.5848097	14.224	8.0923	66.071332
1.45	1.88	0.58	1.88005	0.6218034	14.732	8.3625	70.250851
1.5	1.9197	0.6	1.9197	0.6598009	15.24	8.5388	74.543778
1.55	1.999	0.62	1.99902	0.6989881	15.748	8.8916	78.971116
1.6	2.056	0.64	2.05603	0.7395386	16.256	9.1452	83.552479
1.65	2.1316	0.66	2.13163	0.7814152	16.764	9.4815	88.283664
1.7	2.2184	0.68	2.21838	0.8249153	17.272	9.8674	93.198270
1.75	2.2754	0.7	2.27539	0.869853	17.78	10.121	98.275295
1.8	2.3498	0.72	2.34975	0.9161044	18.288	10.452	103.500742
1.85	2.4365	0.74	2.4365	0.9639669	18.796	10.838	108.908209
1.9	2.5183	0.76	2.5183	1.0135149	19.304	11.201	114.506102
1.95	2.5852	0.78	2.58522	1.0645501	19.812	11.499	12.272019

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
2	2.6534	0.8	2.65338	1.1169361	20.32	11.802	126.190547
2.05	2.7339	0.82	2.73394	1.1708093	20.828	12.161	132.277098
2.1	2.7872	0.84	2.78723	1.2260208	21.336	12.398	138.514859
2.15	2.8628	0.86	2.86283	1.2825217	21.844	12.734	144.898277
2.2	2.9211	0.88	2.92107	1.3403606	22.352	12.993	151.432868
2.25	2.9979	0.9	2.99791	1.3995504	22.86	13.335	158.120084
2.3	3.0686	0.92	3.06855	1.460215	23.368	13.649	164.973922
2.35	3.1342	0.94	3.13424	1.5222427	23.876	13.941	171.981771
2.4	3.2036	0.96	3.20364	1.5856218	24.384	14.25	179.142285
2.45	3.3053	0.98	3.30526	.6507107	24.892	14.702	186.495974
2.5	3.3561	1	3.35608	1.7173241	25.4	14.928	194.021902
2.55	3.4428	1.02	3.44283	1.7853132	25.908	15.314	201.703257
2.6	3.506	1.04	3.50603	1.8548016	26.416	15.595	209.554008
2.65	3.5977	1.06	3.59774	1.9258396	26.924	16.003	217.579822
2.7	3.6795	1.08	3.67954	.9986123	27.432	16.367	225.801618
2.75	3.7626	1.1	3.76257	2.0730334	27.94	16.736	234.209654
2.8	3.832	1.12	3.83197	2.1489788	28.448	17.045	242.789905
2.85	3.9187	1.14	3.91873	2.2264856	28.956	17.431	251.5465
2.9	4.0005	1.16	4.00052	2.305678	29.464	17.794	26.493707
2.95	4.0885	1.18	4.08851	2.3865686	29.972	18.186	269.632611
3	4.1753	1.2	4.17527	2.4692064	30.48	18.572	278.968963
3.05	4.2447	1.22	4.24467	2.5534058	30.988	18.88	288.481744
3.1	4.3054	1.24	4.30539	2.6389062	31.496	19.15	298.141514
3.15	4.4095	1.26	4.4095	2.7260554	32.004	19.613	307.987567
3.2	4.4392	1.28	4.43924	2.8145427	32.512	19.746	317.984782
3.25	4.5186	1.3	4.51856	2.9041207	33.02	20.099	328.105233
3.3	4.583	1.32	4.583	2.9951363	33.528	20.385	338.388103
3.35	4.6363	1.34	4.63629	3.0873290	34.036	20.622	348.803962
3.4	4.7255	1.36	4.72552	3.1809475	34.544	21.019	359.380903
3.45	4.8048	1.38	4.80484	3.2762509	35.052	21.372	370.14820
3.5	4.8693	1.4	4.86928	3.3729921	35.56	21.659	381.07795
3.55	4.9436	1.42	4.94364	3.4711213	36.068	21.989	392.164508
3.6	5.0217	1.44	5.02172	3.5707747	36.576	22.337	403.423270
3.65	5.044	1.46	5.04403	3.6714326	37.084	22.436	414.795519
3.7	5.0862	1.48	5.08616	3.7727343	37.592	22.623	426.240504
3.75	5.1642	1.5	5.16424	3.8752383	38.1	22.971	437.821324
3.8	5.2522	1.52	5.25223	3.9794030	38.608	23.362	449.589769
3.85	5.3452	1.54	5.34518	4.0853769	39.116	23.775	461.562614

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
3.9	5.4034	1.56	5.40343	4.1928634	39.624	24.034	473.706356
3.95	5.4964	1.58	5.49638	4.3018613	40.132	24.448	486.020850
4	5.5633	1.6	5.5633	4.4124581	40.64	24.746	498.515988
4.05	5.624	1.62	5.62403	4.5243318	41.148	25.016	511.155395
4.1	5.681	1.64	5.68104	4.6373818	41.656	25.269	523.927695
4.15	5.7306	1.66	5.73061	4.7514988	42.164	25.49	536.820538
4.2	5.7814	1.68	5.78142	4.8666184	42.672	25.716	549.826659
4.25	5.8484	1.7	5.84835	4.9829166	43.18	26.013	562.965933
4.3	5.9376	1.72	5.93758	5.1007763	43.688	26.41	576.281636
4.35	5.976	1.74	5.976	5.2199114	44.196	26.581	589.741422
4.4	6.0578	1.76	6.05779	5.3402498	44.704	26.945	603.337156
4.45	6.1123	1.78	6.11232	5.4619502	45.212	27.188	617.086766
4.5	6.1892	1.8	6.18916	5.5849655	45.72	27.529	630.984935
4.55	6.2462	1.82	6.24617	5.7093193	46.228	27.783	645.034327
4.6	6.3143	1.84	6.31433	5.8349235	46.736	28.086	659.224995
4.65	6.3763	1.86	6.3763	5.9618303	47.244	28.362	673.562824
4.7	6.4395	1.88	6.4395	6.0899875	47.752	28.643	688.041926
4.75	6.5126	1.9	6.51262	6.2195093	48.26	28.968	702.675186
4.8	6.5882	1.92	6.58822	6.3505182	48.768	29.304	717.476469
4.85	6.6304	1.94	6.63036	6.4827032	49.276	29.492	732.410626
4.9	6.5151	1.96	6.5151	6.6141583	49.784	28.979	747.262321
4.95	6.5969	1.98	6.59689	6.7452774	50.292	29.343	762.076053
5	6.7022	2	6.70224	6.8782693	50.8	29.812	777.101364
5.05	6.784	2.02	6.78403	7.0131325	51.308	30.175	792.338105
5.1	6.8398	2.04	6.8398	7.1493700	51.816	30.423	807.730107
5.15	6.8943	2.06	6.89433	7.2867118	52.324	30.666	823.246879
5.2	6.9885	2.08	6.98852	7.4255395	52.832	31.085	838.931518
5.25	7.0232	2.1	7.02322	7.5656575	53.34	31.239	854.761933
5.3	7.0815	2.12	7.08147	7.7067049	53.848	31.498	870.697363
5.35	7.1707	2.14	7.1707	7.8492258	54.356	31.895	886.799254
5.4	7.2178	2.16	7.21779	7.9931113	54.864	32.105	903.055320
5.45	7.286	2.18	7.28596	8.1381479	55.372	32.408	919.441443
5.5	7.3479	2.2	7.34792	8.2844873	55.88	32.684	935.97475
5.55	7.4012	2.22	7.40121	8.4319792	56.388	32.921	952.638265
5.6	7.4805	2.24	7.48053	8.5807957	56.896	33.273	969.451434
5.65	7.5536	2.26	7.55365	8.7311381	57.404	33.599	986.436998
5.7	7.5933	2.28	7.59331	8.8826068	57.912	33.775	1003.54981
5.75	7.6726	2.3	7.67262	9.0352667	58.42	34.128	1020.797204

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
5.8	7.7272	2.32	7.72715	9.1892650	58.928	34.37	1038.195811
5.85	7.8015	2.34	7.80151	9.3445506	59.436	34.701	1055.739861
5.9	7.8412	2.36	7.84117	9.5009781	59.944	34.878	1073.412906
5.95	7.9081	2.38	7.90809	9.6584697	60.452	35.175	1091.206187
6	7.9663	2.4	7.96634	9.8172147	60.96	35.434	1109.141063
6.05	8.0308	2.42	8.03079	9.9771866	61.468	35.721	1127.214565
6.1	8.0977	2.44	8.09771	10.1384707	61.976	36.019	1145.436306
6.15	8.1498	2.46	8.14976	10.300946	62.484	36.25	1163.792641
6.2	8.1944	2.48	8.19438	10.4643864	62.992	36.449	1182.258009
6.25	8.2625	2.5	8.26254	10.6289563	63.5	36.752	1200.85098
6.3	8.3369	2.52	8.3369	10.7949514	64.008	37.083	1219.604969
6.35	8.3865	2.54	8.38647	10.9621841	64.516	37.303	1238.498785
6.4	8.4571	2.56	8.45711	11.1306205	65.024	37.617	1257.528603
6.45	8.4968	2.58	8.49677	11.3001583	65.532	37.794	1276.682846
6.5	8.5439	2.6	8.54386	11.4705653	66.04	38.003	1295.935291
6.55	8.5897	2.62	8.58972	11.6419018	66.548	38.207	1315.292751
6.6	8.6393	2.64	8.63929	11.8141909	67.056	38.428	1334.757831
6.65	8.7186	2.66	8.71861	11.9877705	67.564	38.78	1354.368726
6.7	8.7595	2.68	8.75951	12.1625507	68.072	38.962	1374.115247
6.75	8.85	2.7	8.84998	12.3386463	68.58	39.365	1394.010388
6.8	8.9082	2.72	8.90822	12.516229	69.088	39.624	1414.073542
6.85	8.9789	2.74	8.97887	12.6950989	69.596	39.938	1434.282112
6.9	9.0346	2.76	9.03463	12.8752346	70.104	40.186	1454.633702
6.95	9.0817	2.78	9.08173	13.0563971	70.612	40.396	1475.101298
7	9.1586	2.8	9.15857	13.2388008	71.12	40.737	1495.709125
7.05	9.2081	2.82	9.20814	13.4224687	71.628	40.958	1516.459771
7.1	9.2515	2.84	9.25152	13.6070642	72.136	41.151	1537.315223
7.15	9.3197	2.86	9.31968	13.7927769	72.644	41.454	1558.2969
7.2	9.2726	2.88	9.27258	13.9786984	73.152	41.244	1579.302161
7.25	9.4163	2.9	9.41634	14.1655883	73.66	41.884	1600.416838
7.3	9.4709	2.92	9.47087	14.3544612	74.168	42.126	1621.755542
7.35	9.5229	2.94	9.52293	14.5443981	74.676	42.358	1643.214457
7.4	9.5985	2.96	9.59852	14.7356133	75.184	42.694	1664.817805
7.45	9.6481	2.98	9.6481	14.9280784	75.692	42.915	1686.562352
7.5	9.7125	3	9.71254	15.1216855	76.2	43.201	1708.435935
7.55	9.7485	3.02	9.74848	15.3162965	76.708	43.361	1730.422927
7.6	9.8253	3.04	9.82532	15.5120333	77.216	43.703	1752.537117
7.65	9.8811	3.06	9.88109	15.7090982	77.724	43.951	1774.801351

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
7.7	9.9505	3.08	9.95049	15.9074128	78.232	44.26	1797.206777
7.75	10.001	3.1	10.0013	16.1069315	78.74	44.486	1819.74824
7.8	10.081	3.12	10.0806	16.3077515	79.248	44.839	1842.436723
7.85	10.128	3.14	10.1277	16.5098336	79.756	45.048	1865.267796
7.9	10.165	3.16	10.1649	16.7127604	80.264	45.213	1888.194305
7.95	10.213	3.18	10.2132	16.9165404	80.772	45.428	1911.217204
8	10.249	3.2	10.2492	17.1211653	81.28	45.588	1934.335553
8.05	10.319	3.22	10.3186	17.3268435	81.788	45.897	1957.572915
8.1	10.374	3.24	10.3743	17.5337734	82.296	46.145	1980.951693
8.15	10.431	3.26	10.4313	17.741827	82.804	46.399	2004.457418
8.2	10.496	3.28	10.4958	17.9510992	83.312	46.685	2028.100828
8.25	10.545	3.3	10.5454	18.1615115	83.82	46.906	2051.873045
8.3	10.626	3.32	10.6259	18.3732252	84.328	47.264	2075.792283
8.35	10.669	3.34	10.6693	18.5861782	84.836	47.457	2099.851549
8.4	10.737	3.36	10.7375	18.8002424	85.344	47.76	2124.036348
8.45	10.78	3.38	10.7796	19.0154139	85.852	47.948	2148.346248
8.5	10.838	3.4	10.8378	19.2315891	86.36	48.207	2172.769557
8.55	10.925	3.42	10.9246	19.4492144	86.868	48.593	2197.356685
8.6	10.984	3.44	10.9841	19.6683021	87.376	48.857	2222.109036
8.65	11.05	3.46	11.0498	19.8886371	87.884	49.149	2247.002306
8.7	11.011	3.48	11.0113	20.1092492	88.392	48.978	2271.926882
8.75	11.101	3.5	11.1006	20.3303693	88.9	49.375	2296.908864
8.8	11.151	3.52	11.1514	20.5528899	89.408	49.601	2322.049062
8.85	11.18	3.54	11.1799	20.7762037	89.916	49.728	2347.278876
8.9	11.246	3.56	11.2456	21.0004549	90.424	50.02	2372.614599
8.95	11.309	3.58	11.3088	21.2259994	90.932	50.301	2398.096436
9	11.367	3.6	11.367	21.4527584	91.44	50.561	2423.715486
9.05	11.436	3.62	11.4364	21.680794	91.948	50.869	2449.478756
9.1	11.492	3.64	11.4922	21.9100812	92.456	51.117	2475.383443
9.15	11.57	3.66	11.5703	22.1407023	92.964	51.465	2501.438831
9.2	11.615	3.68	11.6149	22.372555	93.472	51.663	2527.633366
9.25	11.666	3.7	11.6657	22.605362	93.98	51.889	2553.935719
9.3	11.695	3.72	11.6954	22.8389746	94.488	52.021	2580.329076
9.35	11.774	3.74	11.7735	23.0736653	94.996	52.369	2606.844248
9.4	11.694	3.76	11.6942	23.308339	95.504	52.016	2633.357489
9.45	11.733	3.78	11.7326	23.5426083	96.012	52.187	2659.825051
9.5	11.734	3.8	11.7339	23.7772742	96.52	52.192	2686.33742
9.55	11.712	3.82	11.7116	24.0117295	97.028	52.093	2712.825985

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
9.6	11.764	3.84	11.7636	24.2464821	97.536	52.325	2739.34815
9.65	11.819	3.86	11.8194	24.4823082	98.044	52.573	2765.991597
9.7	11.869	3.88	11.869	24.7191926	98.552	52.793	2792.754602
9.75	11.886	3.9	11.8863	24.9567462	99.06	52.87	2819.593223
9.8	11.946	3.92	11.9458	25.1950682	99.568	53.135	2846.518646
9.85	11.966	3.94	11.9656	25.4341832	100.076	53.223	2873.533675
9.9	12.016	3.96	12.0164	25.674	100.584	53.449	2900.627981
9.95	12.102	3.98	12.1019	25.9151849	101.092	53.829	2927.876854
10	12.106	4	12.1057	26.157262	101.6	53.846	2955.226539
10.05	12.196	4.02	12.1961	26.4002811	102.108	54.248	2982.682639
10.1	12.249	4.04	12.2494	26.6447378	102.616	54.485	3010.301159
10.15	12.284	4.06	12.2841	26.8900695	103.124	54.64	3038.018535
10.2	12.34	4.08	12.3399	27.1363107	103.632	54.888	3065.838679
10.25	12.3	4.1	12.3002	27.3827131	104.14	54.711	3093.677023
10.3	12.358	4.12	12.3585	27.6293014	104.648	54.971	3121.53637
10.35	12.437	4.14	12.4366	27.8772529	105.156	55.318	3149.549731
10.4	12.49	4.16	12.4899	28.1265131	105.664	55.555	3177.710949
10.45	12.543	4.18	12.5431	28.3768442	106.172	55.792	3205.993156
10.5	12.606	4.2	12.6063	28.6283402	106.68	56.073	3234.406973
10.55	12.629	4.22	12.6287	28.8806913	107.188	56.172	3262.9174
10.6	12.675	4.24	12.6745	29.133724	107.696	56.376	3291.504834
10.65	12.743	4.26	12.7427	29.3878919	108.204	56.679	3320.220512
10.7	12.766	4.28	12.7662	29.6429819	108.712	56.784	3349.040378
10.75	12.833	4.3	12.8331	29.8989766	109.22	57.082	3377.962457
10.8	12.838	4.32	12.8381	30.1556901	109.728	57.104	3406.965746
10.85	12.914	4.34	12.9137	30.4132092	110.236	57.44	3436.060041
10.9	12.976	4.36	12.9757	30.6720987	110.744	57.716	3465.309176
10.95	13.019	4.38	13.019	30.9320469	111.252	57.909	3494.677909
11	13.076	4.4	13.076	31.1929988	111.76	58.162	3524.16005
11.05	13.097	4.42	13.0971	31.4547316	112.268	58.256	3553.730407
11.1	13.174	4.44	13.174	31.7174434	112.776	58.598	3583.411382
11.15	13.163	4.46	13.1628	31.9808069	113.284	58.548	3613.165978
11.2	13.186	4.48	13.1863	32.2442995	113.792	58.653	3642.935167
11.25	13.233	4.5	13.2334	32.5084986	114.3	58.862	3672.784165
11.3	13.33	4.52	13.3301	32.7741353	114.808	59.292	3702.795582
11.35	13.308	4.54	13.3078	33.0405155	115.316	59.193	3732.891011
11.4	13.36	4.56	13.3599	33.307188	115.824	59.425	3763.019449
11.45	13.407	4.58	13.407	33.5748571	116.332	59.634	3793.260498

Table 34. Sample of Cantilever Flexure Testing of Guardrail at Room Temperature (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kips)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
11.5	13.426	4.6	13.4255	33.8431831	116.84	59.717	3823.575752
11.55	13.418	4.62	13.4181	34.1116207	117.348	59.684	3853.903614
11.6	0.3792	4.64	0.37923	34.2495946	117.856	1.6868	3869.491801

Note: Maximum values are highlighted.

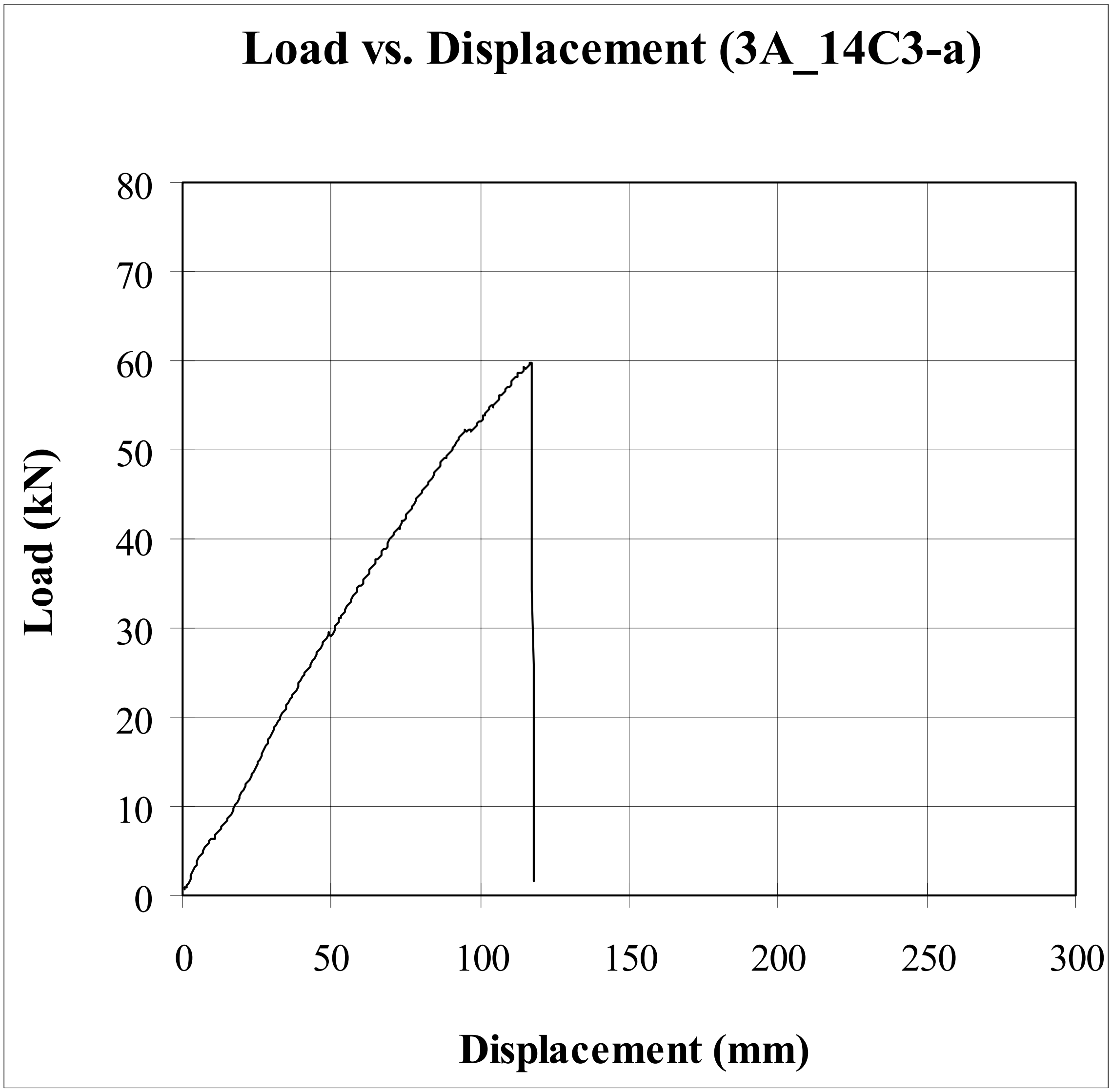

Figure 50. Sample of Load vs. Displacement of Cantilever Flexure Testing of Guardrail at Room Temperature.

Table 35. Sample of Three-Point Bend Test Done on Sign Support at 120 EF.

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
0	0	0.002033333	0.1528	
0.00612	0.00305	0.003815	0.152401706	9.333E-06
0.01104	0.00305	0.005494	0.152082565	0.000024339
0.01866	0.00916	0.006975714	0.151590142	7.08591E-05
0.02716	0.01221	0.009494444	0.151043504	0.000161682
0.03507	0.0061	0.011097273	0.150537316	0.000234098
0.04253	0.01526	0.012441538	0.150062131	0.00031377
0.05119	0.01831	0.013427333	0.149513188	0.000459129
0.0588	0.01831	0.014360588	0.149033172	0.000598468
0.0676	0.01831	0.015418421	0.148480849	0.000759596
0.07506	0.01831	0.017001905	0.148014936	0.000896188
0.08342	0.01831	0.018745714	0.147495321	0.00104926
0.09148	0.02136	0.020489524	0.146996854	0.00120913
0.09984	0.01831	0.022088095	0.14648242	0.001374951
0.10775	0.02136	0.023395714	0.145998094	0.001531845
0.11521	0.02136	0.024558095	0.145543468	0.001691191
0.12327	0.02136	0.026156667	0.145054613	0.001863353
0.13192	0.02441	0.027028571	0.144532662	0.002061308
0.13938	0.02441	0.027900476	0.144084748	0.002243406
0.14759	0.03052	0.028917619	0.143594181	0.002468894
0.15565	0.03357	0.029934762	0.143114995	0.002727177
0.1646	0.03662	0.031242857	0.142585694	0.003041277
0.17221	0.03967	0.032405714	0.142137948	0.003331561
0.18042	0.03662	0.033568571	0.141657273	0.003644731
0.18833	0.03662	0.035021905	0.141196482	0.003934395
0.19564	0.03662	0.036475238	0.140772663	0.004202087
0.20475	0.03967	0.03807381	0.140247189	0.004549588
0.21206	0.03357	0.039381905	0.139827705	0.004817281
0.21997	0.03662	0.04069	0.139375954	0.005094882
0.22862	0.03967	0.041998095	0.138884506	0.005424836
0.23638	0.03967	0.043015238	0.138445897	0.005732675
0.24534	0.04578	0.043741905	0.137942129	0.006115491
0.25235	0.04273	0.044468571	0.137549983	0.006425719
0.26071	0.04578	0.044904762	0.137084588	0.006795691
0.26862	0.04883	0.045921905	0.136646513	0.007169873
0.27742	0.05188	0.046939048	0.13616173	0.007612997
0.28518	0.05493	0.04795619	0.13573649	0.00802742
0.29249	0.04883	0.04897381	0.13533783	0.008406663
0.30115	0.05188	0.050717619	0.134867953	0.008842737
0.30906	0.05188	0.05231619	0.134441041	0.009253108

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
0.31682	0.05188	0.053769524	0.134024325	0.009655697
0.32473	0.04883	0.054932381	0.133601688	0.010054005
0.33279	0.05188	0.055804286	0.133173246	0.010459866
0.34114	0.04883	0.05667619	0.132731732	0.01088033
0.34875	0.05798	0.057693333	0.132331417	0.011286742
0.35771	0.05798	0.058274762	0.131862608	0.011806243
0.36517	0.05798	0.059001429	0.131474356	0.012238774
0.37278	0.06104	0.059873333	0.131080232	0.012691645
0.38188	0.07019	0.060890476	0.130611497	0.013288742
0.3892	0.07019	0.062198571	0.130236463	0.013802532
0.39755	0.07019	0.063360952	0.129810842	0.014388619
0.40546	0.06409	0.064814286	0.129409789	0.014919696
0.41367	0.06409	0.066121905	0.12899572	0.015445875
0.42173	0.06104	0.067139048	0.128591382	0.015950149
0.42964	0.06714	0.068446667	0.128196649	0.016457101
0.43799	0.06104	0.069464286	0.127782187	0.016992253
0.44561	0.06714	0.07033619	0.127405948	0.017480618
0.45441	0.07324	0.071208095	0.1269738	0.01809829
0.46187	0.07019	0.071934286	0.126609425	0.018633284
0.46933	0.07935	0.072370476	0.126246851	0.019191068
0.47814	0.07629	0.073387619	0.125820973	0.019876663
0.4859	0.0824	0.074114286	0.125447918	0.02049238
0.49411	0.07629	0.075276667	0.125055327	0.021143802
0.50097	0.07324	0.07673	0.12472894	0.02165669
0.51007	0.07629	0.078037619	0.124298285	0.022337052
0.51828	0.07935	0.0792	0.123911998	0.022975954
0.52649	0.07629	0.080798571	0.123527838	0.023614856
0.5347	0.07629	0.081815714	0.123145795	0.024241197
0.54216	0.07629	0.082542381	0.122800482	0.02481032
0.55022	0.07935	0.083414286	0.122429347	0.02543755
0.55917	0.09155	0.083704762	0.122019595	0.026202327
0.56633	0.08545	0.084140952	0.121693579	0.026835987
0.57439	0.0885	0.084722381	0.121328476	0.027537006
0.58245	0.09461	0.085594762	0.120965368	0.028274939
0.59081	0.0885	0.086757619	0.120590846	0.029040339
0.59887	0.09155	0.087775238	0.120231782	0.02976594
0.60677	0.09461	0.088937619	0.119881761	0.030501272
0.61528	0.0885	0.090390952	0.119506826	0.031280405
0.62289	0.0885	0.091699048	0.119173392	0.03195389
0.63185	0.0885	0.092861905	0.118783036	0.03274685

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
0.63901	0.08545	0.09373381	0.118472826	0.033369591
0.64722	0.08545	0.094315238	0.118119004	0.034071136
0.65617	0.09461	0.094896667	0.11773557	0.034876904
0.66348	0.09461	0.095478095	0.117424153	0.035568503
0.67139	0.09766	0.09591381	0.117088947	0.036328931
0.67975	0.09766	0.096930952	0.116736666	0.037145369
0.68811	0.10376	0.097657619	0.116386427	0.037987304
0.69601	0.10681	0.09838381	0.116057328	0.038819056
0.70348	0.10376	0.099546667	0.115747806	0.039605535
0.71183	0.10071	0.100854762	0.115403726	0.040459197
0.71989	0.09766	0.102017619	0.115073499	0.041258628
0.7272	0.10376	0.103325714	0.114775608	0.041994818
0.73616	0.09766	0.10463381	0.114412557	0.04289718
0.74302	0.10071	0.10579619	0.114136138	0.043577589
0.75213	0.10376	0.106813333	0.113771114	0.04450895
0.75959	0.10986	0.10754	0.113473945	0.045305752
0.76824	0.10681	0.108266667	0.113131326	0.04624285
0.776	0.10986	0.108848095	0.112825739	0.04708353
0.78436	0.11292	0.109429524	0.112498399	0.04801475
0.79227	0.11597	0.11015619	0.112190462	0.04892001
0.80018	0.11292	0.111028095	0.111884251	0.04982527
0.80883	0.11292	0.112335714	0.111551361	0.050802028
0.81585	0.11292	0.113498095	0.111282705	0.051594727
0.82391	0.11902	0.114805714	0.110975905	0.052529445
0.83256	0.11597	0.116259048	0.110648607	0.053545776
0.83972	0.11292	0.117130952	0.110379217	0.054365203
0.84793	0.11292	0.117567143	0.110072019	0.055292276
0.85614	0.11597	0.118584286	0.109766627	0.056231869
0.86494	0.11902	0.119020476	0.109441284	0.057265825
0.873	0.11902	0.11945619	0.109145103	0.058225127
0.88136	0.11902	0.119891905	0.108839712	0.059220134
0.88927	0.12512	0.120472857	0.108552452	0.060185707
0.89658	0.12817	0.12149	0.10828844	0.061111482
0.90553	0.12512	0.122361905	0.107967094	0.062244955
0.91329	0.13123	0.123379048	0.107690158	0.063239593
0.92076	0.12207	0.12439619	0.107425042	0.064185669
0.92926	0.11902	0.12570381	0.107125117	0.065210301
0.93732	0.12817	0.127011429	0.106842427	0.066206477
0.94538	0.11902	0.128028571	0.106561394	0.067202653
0.95314	0.12207	0.128755238	0.10629238	0.068138082

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
0.96165	0.12512	0.129481905	0.105999115	0.069189875
0.96941	0.12512	0.130208571	0.105733284	0.070160806
0.97717	0.13428	0.130499524	0.105468961	0.071167278
0.98597	0.13123	0.130790476	0.10517103	0.072335522
0.99373	0.14038	0.131371905	0.104909902	0.073389369
1.00179	0.13733	0.131807619	0.104640253	0.07450854
1.00985	0.14038	0.132679524	0.104372201	0.075627712
1.01761	0.14038	0.133841905	0.104115627	0.076717061
1.02567	0.13733	0.134714286	0.103850686	0.077836232
1.03402	0.13428	0.136312857	0.103577873	0.078970204
1.04193	0.13428	0.13776619	0.103320986	0.080032358
1.04954	0.13428	0.139074286	0.103075259	0.081054229
1.05805	0.13123	0.140091905	0.102802109	0.082183974
1.06581	0.13428	0.140673333	0.102554533	0.083214153
1.07357	0.13733	0.1414	0.102308381	0.084268
1.08267	0.14038	0.141690952	0.102021528	0.08553158
1.08984	0.14038	0.142127143	0.10179688	0.086538105
1.09789	0.14343	0.142563333	0.101546087	0.08768044
1.10625	0.14649	0.142999524	0.101287227	0.088892306
1.11461	0.15259	0.14372619	0.101029979	0.09014246
1.12252	0.15259	0.144598095	0.100788055	0.091349447
1.12953	0.15259	0.145615238	0.100574852	0.092419103
1.13804	0.14649	0.146777619	0.100317528	0.093691688
1.14639	0.14649	0.148085238	0.100066634	0.09491488
1.15415	0.14649	0.149247619	0.099834874	0.096051642
1.16266	0.14649	0.150119524	0.099582264	0.097298272
1.17042	0.14649	0.150991429	0.099353322	0.098435035
1.17863	0.14954	0.151718095	0.099112558	0.099650223
1.18713	0.14954	0.152154286	0.098864848	0.100921328
1.19519	0.15259	0.152735238	0.098631426	0.102138912
1.2031	0.15259	0.153025714	0.098403723	0.103345899
1.21161	0.15564	0.15331619	0.098160264	0.104657417
1.21982	0.15869	0.153897619	0.097926866	0.105947742
1.22728	0.15869	0.154769524	0.097716042	0.107131569
1.23593	0.15869	0.155786667	0.097473074	0.108504238
1.24339	0.15564	0.15680381	0.097264806	0.109676689
1.251	0.15869	0.158111429	0.09705356	0.110872714
1.25981	0.15564	0.15927381	0.096810521	0.112257338
1.26697	0.15259	0.160145714	0.096614193	0.113360802
1.27548	0.15869	0.160872381	0.096382231	0.114685298

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
1.28369	0.15869	0.161744286	0.096159863	0.115988143
1.29189	0.15869	0.16261619	0.095939146	0.117289401
1.29995	0.1648	0.163052381	0.095723533	0.118593066
1.30726	0.1648	0.163343333	0.095529124	0.119797754
1.31562	0.16785	0.163779524	0.095308111	0.121188231
1.32353	0.16785	0.16450619	0.095100285	0.122515924
1.33129	0.17395	0.165378095	0.094897612	0.123842108
1.3401	0.1709	0.16625	0.094668964	0.125361172
1.34696	0.16785	0.167412381	0.094491983	0.126523085
1.35547	0.1648	0.168865714	0.094273716	0.127938511
1.36382	0.1709	0.170028571	0.094060925	0.129340058
1.37218	0.1709	0.171191429	0.093849228	0.130768799
1.37994	0.1648	0.172063333	0.093653933	0.132071298
1.388	0.1648	0.172789524	0.093452305	0.133399586
1.39621	0.16785	0.173515714	0.093248194	0.134765115
1.40412	0.17395	0.174096667	0.093052746	0.136116934
1.41322	0.17395	0.174387143	0.092829348	0.137699879
1.42068	0.177	0.174532381	0.092647363	0.139008922
1.42814	0.18005	0.17511381	0.09246641	0.140340719
1.43724	0.18311	0.175985714	0.092247065	0.141993097
1.44486	0.18311	0.176857619	0.092064558	0.143388413
1.45321	0.18311	0.177584286	0.091865786	0.144917345
1.46067	0.177	0.17845619	0.091689263	0.146260555
1.46918	0.18005	0.17976381	0.09148911	0.147779839
1.47709	0.18005	0.181071429	0.091304234	0.149204016
1.485	0.18005	0.18223381	0.091120466	0.150628212
1.49321	0.17395	0.182815238	0.090930893	0.152081382
1.50037	0.177	0.183687143	0.090766528	0.153337783
1.50917	0.18311	0.184268571	0.090565737	0.154922267
1.51723	0.18616	0.184559524	0.090383004	0.156410425
1.5244	0.18311	0.18485	0.090221387	0.157734239
1.53305	0.18616	0.185140476	0.090027571	0.15933135
1.54096	0.18921	0.185430952	0.089851447	0.160815939
1.54947	0.19226	0.186302857	0.089663138	0.162439094
1.55738	0.19226	0.187029524	0.089489189	0.16395987
1.56543	0.19226	0.187901429	0.089313226	0.165507563
1.5726	0.18616	0.188773333	0.089157397	0.166864199
1.5811	0.19226	0.190081429	0.088973749	0.168472503
1.59006	0.18921	0.191098571	0.088781439	0.17018145
1.59752	0.18616	0.191824762	0.088622307	0.17158158

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
1.60558	0.18921	0.192260476	0.088451373	0.17309434
1.61423	0.18921	0.192986667	0.088269078	0.174731007
1.62184	0.18921	0.193277143	0.088109674	0.176170895
1.6302	0.19531	0.193567619	0.087935606	0.177778189
1.63781	0.19531	0.193858095	0.087778099	0.179264478
1.64706	0.19836	0.194439524	0.087587845	0.181085222
1.65408	0.19836	0.195020952	0.087444333	0.182477709
1.66288	0.20142	0.195892857	0.087265487	0.184236741
1.67049	0.19836	0.196474286	0.087111767	0.185757904
1.67766	0.19836	0.19734619	0.086967725	0.187180165
1.68661	0.19531	0.198363333	0.086788996	0.188941838
1.69392	0.19836	0.19909	0.086643894	0.190380682
1.70198	0.19226	0.199816667	0.086484809	0.191954861
1.70989	0.19531	0.200688571	0.086329596	0.19348772
1.71795	0.19836	0.200979524	0.086172365	0.19507423
1.7266	0.20447	0.201415714	0.086004659	0.196816449
1.73377	0.20447	0.201706667	0.085866448	0.198282499
1.74227	0.20447	0.202142857	0.085703535	0.200020474
1.75078	0.20447	0.20272381	0.085541432	0.201760554
1.75735	0.20752	0.203305238	0.085416972	0.203113921
1.7669	0.20752	0.204177619	0.085237109	0.205095737
1.77406	0.20447	0.205340476	0.085103071	0.206570661
1.78286	0.20447	0.206358095	0.084939275	0.208369997
1.79107	0.20752	0.207520952	0.08478739	0.210061237
1.79928	0.20142	0.208392857	0.0846364	0.211739915
1.80704	0.20447	0.209265238	0.084494494	0.213314768
1.8154	0.20447	0.209846667	0.084342491	0.215024137
1.8236	0.20752	0.210282381	0.08419427	0.216713296
1.83166	0.21362	0.210572857	0.084049415	0.21841049
1.84017	0.21057	0.210863333	0.083897362	0.220215419
1.84748	0.21668	0.21115381	0.083767473	0.221777018
1.85539	0.21973	0.211735238	0.083627669	0.223503019
1.86345	0.21973	0.212461905	0.083486005	0.225274043
1.87151	0.21668	0.213188571	0.083345131	0.227032775
1.87912	0.21362	0.21377	0.083212842	0.228670045
1.88747	0.21668	0.214932381	0.083068481	0.230466569
1.89598	0.21668	0.215949524	0.082922204	0.232310516
1.90374	0.21362	0.216821429	0.082789557	0.23398008
1.9115	0.21057	0.217693333	0.082657608	0.235625937
1.92016	0.21057	0.218274762	0.082511171	0.237449474

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
1.92747	0.21362	0.21885619	0.082388225	0.238999888
1.93478	0.21973	0.219001429	0.082265879	0.240583782
1.94433	0.21973	0.219291905	0.08210694	0.242682204
1.95149	0.21973	0.219582381	0.081988435	0.244255471
1.96015	0.21973	0.220163333	0.081845851	0.246158332
1.96821	0.22583	0.22089	0.08171387	0.247953961
1.97597	0.22583	0.221470952	0.081587458	0.24970638
1.98433	0.22278	0.222342857	0.081451982	0.251581569
1.99253	0.22583	0.223505714	0.081319804	0.253420893
2.00014	0.22583	0.22481381	0.08119776	0.255139437
2.00775	0.22278	0.225830952	0.081076304	0.25684642
2.01671	0.21973	0.226702857	0.080934051	0.258828865
2.02387	0.22583	0.22728381	0.080820952	0.26042397
2.03148	0.22583	0.228010476	0.080701301	0.262142491
2.04118	0.22888	0.22844619	0.080549601	0.264347857
2.04849	0.22888	0.229172857	0.080435876	0.266020993
2.0567	0.22888	0.229463333	0.080308757	0.267900098
2.06506	0.23499	0.229899524	0.080179966	0.269839051
2.07327	0.23804	0.23062619	0.080054117	0.271780815
2.08118	0.23804	0.231207619	0.079933448	0.273663712
2.08923	0.23193	0.231789048	0.079811223	0.275555341
2.09714	0.23193	0.23280619	0.079691686	0.277389907
2.10505	0.23193	0.233968571	0.0795727	0.279224474
2.11386	0.23499	0.234840476	0.079440814	0.28128128
2.12102	0.22888	0.235567143	0.079334121	0.282941911
2.12863	0.23499	0.236148571	0.079221195	0.28470696
2.13714	0.23193	0.237020476	0.079095486	0.286693728
2.14505	0.23499	0.237456667	0.078979176	0.288540396
2.1534	0.23804	0.237747143	0.078856948	0.290515273
2.16116	0.23804	0.237892381	0.078743853	0.292362487
2.16982	0.23804	0.238182857	0.078618206	0.294423866
2.17788	0.24414	0.238764286	0.078501781	0.296367099
2.18564	0.24414	0.239345714	0.078390165	0.298261577
2.19444	0.24414	0.239927143	0.078264132	0.300410033
2.20176	0.24109	0.240799048	0.078159736	0.302185951
2.20922	0.24109	0.242107143	0.078053743	0.303984506
2.21832	0.24719	0.242833333	0.07792499	0.30620618
2.22548	0.23804	0.243850952	0.077824099	0.307943279
2.23429	0.24109	0.244431905	0.077700443	0.310053871
2.24205	0.24109	0.245158571	0.077591965	0.31192473

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
2.25055	0.24414	0.245739524	0.077473605	0.313986981
2.25816	0.24414	0.246320476	0.077368046	0.315844838
2.26622	0.24414	0.246610952	0.077256651	0.317812606
2.27413	0.24414	0.24675619	0.077147732	0.319743754
2.28174	0.2533	0.247192381	0.077043312	0.321636538
2.29055	0.25635	0.247919048	0.07692287	0.323881571
2.29816	0.25024	0.248790952	0.076819213	0.325809096
2.30607	0.2533	0.249517619	0.07671183	0.327800596
2.31428	0.24719	0.25068	0.076600755	0.329855158
2.32233	0.2533	0.251842381	0.076492218	0.33186963
2.33069	0.25024	0.252859524	0.076379884	0.333974402
2.3389	0.25024	0.253440952	0.076269936	0.336028848
2.34696	0.25024	0.254022381	0.076162344	0.338045782
2.35472	0.24719	0.254749048	0.076059076	0.33997581
2.36233	0.2533	0.255330476	0.075958101	0.3418802
2.37098	0.25635	0.255475714	0.075843676	0.344084462
2.37844	0.2594	0.255475714	0.075745288	0.346008183
2.3868	0.26245	0.256057143	0.075635344	0.34818949
2.39486	0.26245	0.256638095	0.075529648	0.35030489
2.40277	0.2655	0.25751	0.075426206	0.352392932
2.41053	0.26245	0.258236667	0.075324996	0.354441325
2.41874	0.25635	0.259109048	0.075218193	0.356571051
2.42739	0.25635	0.259981429	0.075105975	0.358788427
2.43545	0.2594	0.26085381	0.075001682	0.3608669
2.44396	0.25635	0.261725714	0.074891841	0.363061442
2.45172	0.25635	0.262452381	0.074791921	0.365050743
2.45918	0.25635	0.262888095	0.074696078	0.366963063
2.46828	0.26245	0.263033333	0.074579431	0.369323603
2.47559	0.2655	0.263178571	0.074485934	0.371253313
2.48335	0.2655	0.263614762	0.074386881	0.373313593
2.49171	0.26856	0.263905714	0.074280387	0.375545937
2.49977	0.26856	0.264487143	0.074177921	0.377710531
2.50783	0.26856	0.265359048	0.07407565	0.379875125
2.51574	0.26856	0.266521429	0.073975464	0.381999434
2.52424	0.2655	0.267393333	0.073867998	0.384269216
2.5323	0.26856	0.26812	0.073766273	0.386421478
2.53932	0.2655	0.268846667	0.073677808	0.388296028
2.54857	0.26245	0.269718571	0.073561425	0.390737771
2.55588	0.2655	0.2703	0.07346959	0.392667401
2.56498	0.27161	0.270590952	0.073355428	0.395111306

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
2.57259	0.27161	0.271027143	0.073260094	0.397178203
2.58035	0.27466	0.271172381	0.073162994	0.399297758
2.58811	0.27466	0.271462857	0.073066006	0.40142912
2.59647	0.28076	0.272189048	0.072961637	0.403750748
2.60468	0.27771	0.272915238	0.072859249	0.406043267
2.61199	0.27161	0.273787143	0.072768169	0.408051059
2.6205	0.27161	0.274659048	0.072662232	0.410362433
2.6287	0.27466	0.275676667	0.072560238	0.412602195
2.63632	0.27466	0.27669381	0.072465532	0.414695049
2.64512	0.27161	0.277711429	0.072356231	0.417098664
2.65258	0.27466	0.278438095	0.072263629	0.419136279
2.66094	0.27161	0.279019048	0.07215991	0.42141966
2.6693	0.27466	0.279454762	0.072056239	0.423703041
2.67765	0.28381	0.279890476	0.071952729	0.426034681
2.68496	0.28381	0.280035714	0.071862137	0.428109333
2.69377	0.28381	0.280617143	0.07175298	0.430609699
2.70138	0.28687	0.281489048	0.071658703	0.432781165
2.70899	0.28687	0.282215714	0.071564436	0.434964188
2.7175	0.28381	0.282942381	0.071459016	0.43739246
2.72511	0.28687	0.283669048	0.071364738	0.439563869
2.73302	0.28687	0.284831429	0.071266728	0.44183301
2.74122	0.28381	0.285848571	0.071165099	0.444172855
2.74958	0.28381	0.286575238	0.071061458	0.446545479
2.75704	0.28381	0.287447143	0.070968937	0.44866273
2.76555	0.28381	0.287883333	0.070863348	0.451077924
2.77435	0.28992	0.288174286	0.070754097	0.453602336
2.78211	0.28992	0.288465238	0.070657697	0.455852116
2.78913	0.28687	0.288755714	0.070570435	0.457876649
2.79793	0.28992	0.28904619	0.070460963	0.460414553
2.80569	0.28992	0.289627619	0.07036435	0.462664275
2.81375	0.29602	0.289918095	0.070263908	0.465025671
2.82196	0.29602	0.29035381	0.070161498	0.467455966
2.82942	0.28687	0.291080476	0.070068349	0.469630117
2.83837	0.29297	0.291807143	0.069956464	0.472224901
2.84613	0.29297	0.29253381	0.069859334	0.474498377
2.85464	0.28992	0.293405714	0.069752678	0.476978603
2.8627	0.28992	0.293986667	0.069651523	0.479315358
2.87091	0.29297	0.294422381	0.069548338	0.481708093
2.87897	0.29297	0.295003333	0.069446884	0.484069431
2.88628	0.29602	0.29529381	0.069354733	0.48622216

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
2.89478	0.29297	0.295729524	0.069247406	0.488725397
2.9021	0.29602	0.295874762	0.069154826	0.490881071
2.91105	0.29907	0.296310952	0.069041425	0.493544098
2.91866	0.29907	0.297037143	0.068944818	0.495820051
2.92657	0.29907	0.297472857	0.068844217	0.498185695
2.93478	0.30212	0.298199524	0.068739593	0.50065358
2.94209	0.30212	0.299071429	0.068646252	0.502862107
2.95104	0.29907	0.299943333	0.068531727	0.505552432
2.9588	0.29907	0.30067	0.068432205	0.507873156
2.96656	0.29602	0.301105714	0.068332461	0.510182135
2.97537	0.29907	0.301832381	0.068218952	0.512803506
2.98313	0.29907	0.30241381	0.068118724	0.515124289
2.99134	0.30518	0.302704286	0.068012424	0.517604736
2.99939	0.30212	0.302995238	0.067907929	0.520049118
3.00715	0.30212	0.303431429	0.067806942	0.522393569
3.01536	0.30823	0.303722381	0.067699817	0.524899026
3.02327	0.30823	0.30430381	0.067596323	0.527337156
3.03163	0.30823	0.304885238	0.067486632	0.529913989
3.03909	0.30823	0.305611905	0.067388478	0.532213354
3.04745	0.30212	0.306629524	0.067278167	0.534764587
3.05595	0.31128	0.307792381	0.067165656	0.537371567
3.06341	0.30518	0.308664286	0.067066613	0.539670994
3.07237	0.30212	0.309390952	0.066947283	0.542391637
3.07998	0.30518	0.309681429	0.066845599	0.544702444
3.08819	0.30823	0.310408095	0.066735552	0.547220462
3.09639	0.30518	0.310699048	0.066625268	0.549735504
3.1046	0.31433	0.310844286	0.066514477	0.552278561
3.11221	0.31433	0.311134762	0.066411437	0.554670644
3.12027	0.31433	0.311425238	0.066301937	0.557204144
3.12893	0.32044	0.311860952	0.06618386	0.559952635
3.13654	0.32044	0.312733333	0.06607972	0.562391215
3.1443	0.31738	0.313169524	0.06597316	0.564865989
3.15265	0.31433	0.314041429	0.06585808	0.567503315
3.16012	0.31128	0.315059048	0.065754745	0.569840031
3.16862	0.31738	0.315930952	0.065636726	0.572511773
3.17653	0.30823	0.316512381	0.065526465	0.574986092
3.18399	0.31128	0.317239048	0.06542209	0.577296895
3.19205	0.31433	0.31753	0.065308895	0.579818072
3.19996	0.31433	0.317820952	0.065197364	0.582304454
3.20847	0.31738	0.31796619	0.065076882	0.584992316

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
3.21667	0.32044	0.317820476	0.06496029	0.587607442
3.22533	0.32044	0.317674762	0.064836629	0.590382389
3.23339	0.32349	0.317965714	0.064721031	0.592977426
3.24145	0.32349	0.318692381	0.064604943	0.595584756
3.2498	0.32349	0.319419048	0.06448415	0.59828593
3.25682	0.32044	0.320000476	0.064382178	0.600546124
3.26488	0.32044	0.321162857	0.064264619	0.60312887
3.27279	0.32044	0.322034762	0.064148741	0.605663551
3.28099	0.32044	0.322906667	0.064028078	0.608291159
3.2892	0.31738	0.323342857	0.063906714	0.610909378
3.29666	0.31738	0.323779048	0.063795945	0.613277065
3.30562	0.31738	0.324214762	0.063662282	0.616120789
3.31338	0.32349	0.324650476	0.063545961	0.618607397
3.32233	0.32959	0.324795714	0.063411152	0.62152993
3.32994	0.32654	0.324940952	0.063295973	0.624026439
3.33785	0.32959	0.325231429	0.063175701	0.626621433
3.34621	0.33264	0.325812381	0.063047966	0.629389621
3.35382	0.32959	0.326248095	0.062931139	0.63190934
3.36188	0.33264	0.326829048	0.062806814	0.634578127
3.36919	0.32349	0.327555238	0.062693527	0.636976315
3.37829	0.32654	0.328718095	0.06255179	0.639933951
3.38575	0.32959	0.329880952	0.062435003	0.642381283
3.39292	0.32959	0.330898571	0.06232224	0.644744509
3.40262	0.32654	0.331479524	0.062168888	0.647926674
3.41023	0.32654	0.33177	0.062047915	0.650411676
3.41814	0.32959	0.332351429	0.061921554	0.65300667
3.42694	0.33264	0.332641905	0.061780225	0.655920482
3.43425	0.32959	0.332641905	0.061662217	0.6583409
3.44231	0.33264	0.332932381	0.061531453	0.661009687
3.45022	0.33569	0.333077619	0.061402455	0.663652932
3.45843	0.3418	0.333804286	0.061267857	0.666434029
3.46634	0.3418	0.334530952	0.061137489	0.669137667
3.47514	0.33875	0.335112381	0.06099165	0.672132087
3.48275	0.33569	0.335839048	0.060864841	0.674698364
3.49051	0.33569	0.33685619	0.060734868	0.677303352
3.49932	0.33875	0.337728095	0.060586488	0.680274261
3.50723	0.33569	0.338454762	0.060452512	0.682941671
3.51439	0.33264	0.339181429	0.06033062	0.685334292
3.52305	0.33569	0.339908095	0.060182399	0.688228094
3.53081	0.33569	0.340489524	0.060048832	0.690833049

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
3.53901	0.33875	0.340925714	0.059906913	0.69359832
3.54692	0.3418	0.340925714	0.059769257	0.696289827
3.55483	0.3418	0.341070952	0.059630843	0.698993465
3.56259	0.34485	0.34121619	0.059494311	0.701657702
3.57095	0.3479	0.342088095	0.059346393	0.704553431
3.5799	0.34485	0.342814762	0.059187075	0.707653488
3.58736	0.34485	0.343395714	0.059053515	0.710226034
3.59557	0.3479	0.344413333	0.058905712	0.713069738
3.60363	0.34485	0.34557619	0.058759771	0.715861521
3.61154	0.34485	0.34659381	0.058615731	0.718589284
3.61915	0.34485	0.347611429	0.058476384	0.721213627
3.62706	0.3418	0.348192381	0.058330741	0.723929328
3.63691	0.34485	0.348628095	0.058148219	0.727311079
3.64288	0.3418	0.349209048	0.058036964	0.729360729
3.65198	0.354	0.349499524	0.057866455	0.732526619
3.66019	0.35095	0.349644762	0.057711659	0.735420404
3.6675	0.35095	0.349935238	0.057573049	0.737985919
3.67675	0.35706	0.350225714	0.057396602	0.741260429
3.68436	0.35706	0.350661905	0.05725054	0.743977692
3.69198	0.35706	0.351243333	0.057103475	0.746698453
3.70003	0.35706	0.351824762	0.056947218	0.749572751
3.70764	0.35095	0.352551429	0.056798647	0.752266764
3.71645	0.35095	0.353568571	0.056625609	0.755358633
3.72421	0.354	0.354585714	0.056472259	0.758093875
3.73301	0.35095	0.355602857	0.056297297	0.761195584
3.74107	0.35095	0.355748571	0.056136038	0.764024311
3.74794	0.35095	0.356184762	0.055997832	0.766435268
3.75689	0.35095	0.35676619	0.055816717	0.76957627
3.7642	0.35706	0.356911429	0.055667891	0.772164082
3.77241	0.35706	0.356765714	0.055499774	0.775095545
3.78002	0.35706	0.35662	0.05534302	0.777812807
3.78838	0.36011	0.356765238	0.055169791	0.780810542
3.79718	0.36316	0.357491905	0.054986267	0.78399293
3.80509	0.36621	0.358073333	0.054820269	0.786877588
3.8139	0.36316	0.358509524	0.054634218	0.790090499
3.82106	0.35706	0.359381429	0.054482105	0.792668851
3.82957	0.36011	0.360108095	0.054300244	0.795720374
3.83718	0.36316	0.360834762	0.054136621	0.798472452
3.84374	0.36011	0.361561429	0.053994819	0.800844814
3.85285	0.354	0.361851905	0.053796733	0.804097549

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
3.86031	0.354	0.362287619	0.053633506	0.806738354
3.86926	0.36011	0.362578095	0.053436457	0.809933996
3.87777	0.36621	0.362868571	0.053247851	0.813024524
3.88568	0.36316	0.363159048	0.053071451	0.815909182
3.89403	0.36316	0.363159048	0.052884091	0.818941532
3.90194	0.36926	0.363449524	0.052705503	0.821838253
3.91015	0.36621	0.36417619	0.052519004	0.824857357
3.91731	0.36621	0.364611905	0.052355401	0.827479494
3.92567	0.36621	0.365338571	0.052163256	0.830540973
3.93313	0.36316	0.36592	0.051990757	0.83326156
3.94134	0.36621	0.367082857	0.051799787	0.836255587
3.94985	0.36316	0.368100476	0.051600575	0.83935902
3.9582	0.36621	0.36853619	0.051403846	0.842404176
3.96656	0.36926	0.368972381	0.051205626	0.845478441
3.97432	0.36621	0.36955381	0.0510205	0.848332065
3.98238	0.36926	0.369699048	0.050827054	0.851296009
3.99029	0.37232	0.369844762	0.050636049	0.854228958
3.99745	0.36926	0.370135714	0.050462162	0.856883777
4.00581	0.37842	0.370717143	0.050257924	0.860009079
4.01431	0.37232	0.371298571	0.050048925	0.863199762
4.02282	0.37842	0.372025238	0.049838318	0.866394198
4.03088	0.37537	0.372606667	0.049637589	0.869431934
4.03849	0.36926	0.373478571	0.049446932	0.872265214
4.04715	0.37537	0.374205238	0.049228608	0.875489574
4.05461	0.37537	0.374786667	0.049039395	0.878289684
4.06296	0.36621	0.375513333	0.048826307	0.881385928
4.06998	0.37232	0.376094762	0.048646116	0.883978169
4.07878	0.37232	0.376385238	0.048418881	0.887254436
4.08714	0.37842	0.37667619	0.048201572	0.890392679
4.09445	0.37842	0.376821429	0.048010432	0.893158891
4.10341	0.37842	0.377111905	0.047774697	0.896549421
4.11087	0.37842	0.377257143	0.047577184	0.89937251
4.11863	0.38147	0.377692857	0.047370542	0.902320883
4.12728	0.38147	0.378419524	0.047138763	0.905620522
4.13519	0.38147	0.378855238	0.046925462	0.908638065
4.14325	0.38147	0.37943619	0.046706801	0.911712713
4.15041	0.38147	0.380744286	0.046511439	0.914443924
4.15922	0.37842	0.38161619	0.046269586	0.917791239
4.16683	0.37537	0.382488095	0.046059362	0.920659523
4.17474	0.38147	0.38292381	0.045839575	0.92365275

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
4.18384	0.37842	0.383359524	0.045585082	0.927110249
4.1919	0.38147	0.383795238	0.045358207	0.930172568
4.19996	0.38452	0.384085714	0.045129942	0.933259507
4.20787	0.38452	0.384230952	0.04490456	0.936301176
4.21488	0.38452	0.384521429	0.0447037	0.938996661
4.22354	0.38757	0.384811905	0.044454096	0.942339734
4.2313	0.39368	0.385393333	0.044229037	0.945370984
4.2398	0.39063	0.385829524	0.043980998	0.94870434
4.24831	0.39063	0.38655619	0.043731067	0.95202868
4.25652	0.38757	0.387428095	0.04348844	0.955223074
4.26413	0.38757	0.388154762	0.043262186	0.958172598
4.27114	0.38757	0.388881429	0.043052631	0.960889464
4.28054	0.38452	0.389462857	0.042769896	0.964518248
4.28726	0.38452	0.389899048	0.042566543	0.967102223
4.29621	0.38757	0.39019	0.042294119	0.970557248
4.30487	0.38757	0.390480952	0.042028763	0.973913721
4.31263	0.39368	0.390626667	0.041789542	0.976944814
4.32098	0.39063	0.390481429	0.041530555	0.980219426
4.3283	0.39368	0.390481429	0.041302192	0.983090001
4.3365	0.39368	0.391062381	0.041044887	0.986318216
4.34411	0.39673	0.391789048	0.040804692	0.989325687
4.35143	0.39368	0.392515714	0.040572363	0.992218548
4.36098	0.39368	0.393242381	0.040267342	0.995978231
4.36874	0.39368	0.39382381	0.040017895	0.999033227
4.37724	0.39063	0.394695714	0.039743023	1.002366388
4.385	0.39063	0.395422381	0.039490554	1.005397677
4.39276	0.39063	0.395713333	0.039236628	1.008429005
4.40037	0.39063	0.39600381	0.038986185	1.011401816
4.40828	0.39063	0.396439524	0.03872439	1.014491621
4.41724	0.40283	0.396584762	0.038425979	1.018046401
4.425	0.40283	0.396875238	0.038165957	1.021172201
4.4338	0.40283	0.39673	0.03786927	1.024717105
4.44186	0.40283	0.397165714	0.037595843	1.027963915
4.44902	0.39673	0.397310952	0.037351581	1.03082642
4.45783	0.40283	0.397746667	0.037049275	1.034348481
4.46439	0.40283	0.398472857	0.036822909	1.036991006
4.47305	0.39368	0.39368	0.036522396	1.040440014
4.48141	0.39978	0.39978	0.036230499	1.043756637
4.48961	0.39978	0.39978	0.035942462	1.047034713
4.49827	0.39673	0.39673	0.035636373	1.050483721

Table 35. Sample of Three Point Bend Test Done on Sign Support at 120 EF (Continued).

Disp (in)	Load (kips)	Avg'd load (kips)	Derivative-Slope (kip/in)	Energy (kip-in)
4.50603	0.39978	0.39978	0.035360458	1.053574219

Note: Maximum values are highlighted.

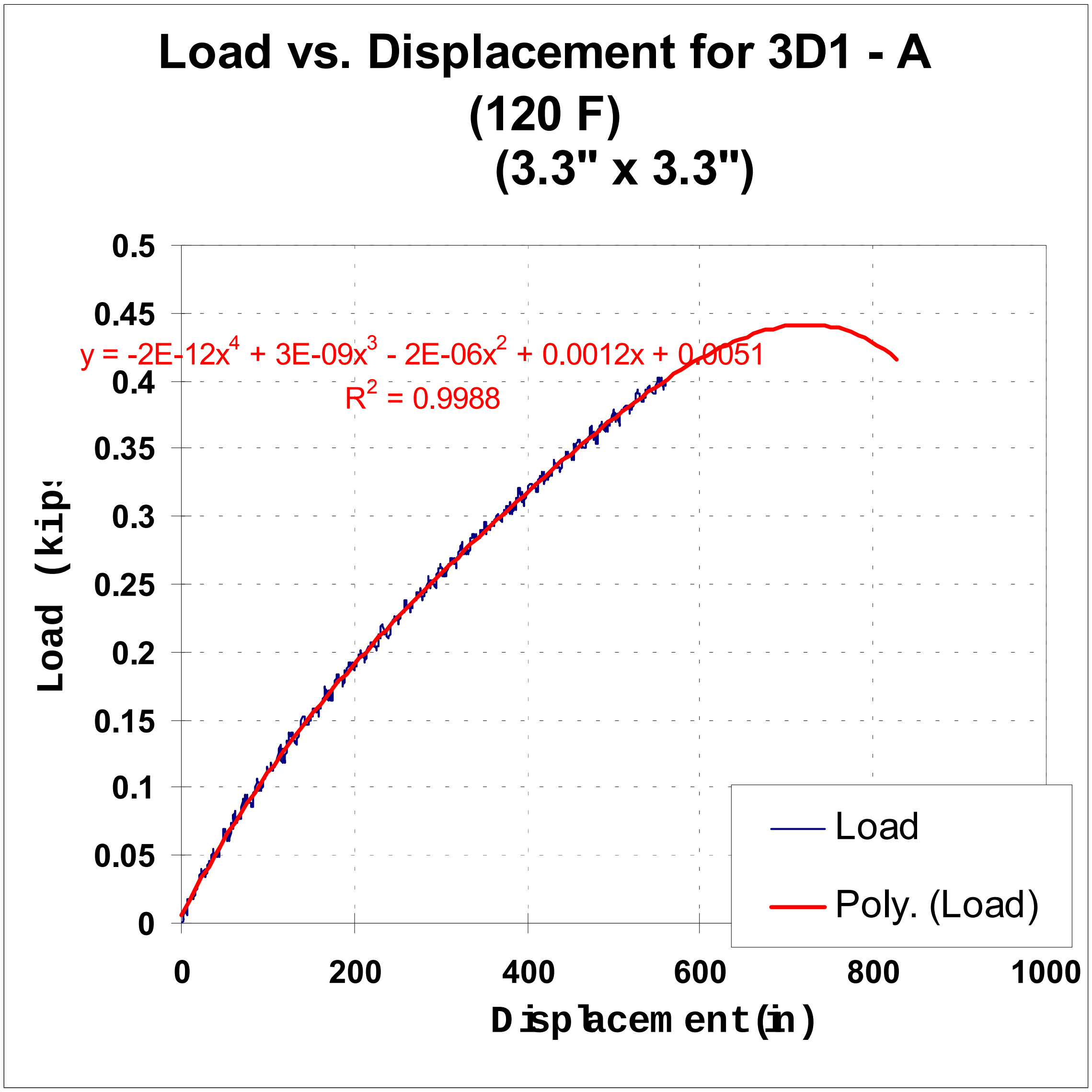

Figure 51. Sample of Load vs. Displacement for 3.D.1-A (120 EF).

Table 36. Sample of Energy Absorption Obtained from Hydrocon Testing on Guardrail 3.C.4.

Time (sec)	Load (kips)	Displ. (in)	Load (kip)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
0	0.06322	0	0.06322		0	0.281203	
0.2	0.23553	0.08	0.23553	0.01195	2.032	1.047637	1.3501014
0.4	0.42147	0.16	0.42147	0.03823	4.064	1.874699	4.3191948
0.6	0.59006	0.24	0.59006	0.0786912	6.096	2.624587	8.8904688
0.8	0.76485	0.32	0.76485	0.1328876	8.128	3.402053	15.0135347
1	0.92724	0.4	0.92724	0.2005712	10.16	4.124364	22.6603737
1.2	1.09335	0.48	1.0933501	0.2813948	12.192	4.863221	31.7917598
1.4	1.2669	0.56	1.2668999	0.3758048	14.224	5.635171	42.4581261
1.6	1.44664	0.64	1.44664	0.4843464	16.256	6.434655	54.7210687
1.8	1.63754	0.72	1.63754	0.6077136	18.288	7.283778	68.6589963
2	1.81233	0.8	1.81233	0.7457084	20.32	8.061244	84.2495384
2.2	1.98464	0.88	1.98464	0.8975872	22.352	8.827679	101.408683
2.4	2.13339	0.96	2.1333899	1.0623084	24.384001	9.489318	120.018762
2.6	2.28835	1.04	2.2883501	1.2391779	26.415999	10.17858	140.001328
2.8	2.44578	1.12	2.44578	1.4285432	28.448	10.87883	161.395667
3	2.59825	1.2	2.5982499	1.6303043	30.48	11.55702	184.190486
3.2	2.78048	1.28	2.7804799	1.8454535	32.512	12.36757	208.49787
3.4	2.91931	1.36	2.9193101	2.0734453	34.544001	12.98509	234.256191
3.6	3.07923	1.44	3.0792301	2.3133866	36.575999	13.69642	261.3645753
3.8	3.22426	1.52	3.2242601	2.5655264	38.608	14.34151	289.8511207
4	3.36558	1.6	3.3655801	2.8291200	40.64	14.9701	319.6317157
4.2	3.51309	1.679	3.5130899	3.1042665	42.671998	15.62622	350.71755
4.4	3.67301	1.76	3.6730101	3.3917109	44.704001	16.33755	383.1927918
4.6	3.823	1.84	3.823	3.6915510	46.735999	17.0047	417.0684869
4.8	3.94324	1.920	3.9432399	4.0022011	48.768002	17.53953	452.1654824
5	4.0796	2	4.0795999	4.3231144	50.8	18.14606	488.422007
5.2	4.211	2.079	4.211	4.6547380	52.831998	18.73053	525.8885833
5.4	4.34984	2.16	4.3498402	4.9971721	54.864001	19.34809	564.5765165
5.6	4.4862	2.24	4.4861999	5.3506134	56.895999	19.95462	604.5080262
5.8	4.64487	2.320	4.6448698	5.7158567	58.928002	20.66038	645.7729261
6	4.78495	2.4	4.7849498	6.0930491	60.96	21.28346	688.3878225
6.2	4.90147	2.479	4.9014702	6.4805055	62.991998	21.80174	732.162338
6.4	5.02915	2.56	5.02915	6.8777310	65.024001	22.36966	777.0405463
6.6	5.18659	2.64	5.1865902	7.2863602	67.055999	23.06995	823.2071464
6.8	5.32542	2.720	5.3254199	7.7068412	69.088002	23.68747	870.7127573
7	5.45806	2.8	5.4580598	8.1381799	71.12	24.27745	919.4450649
7.2	5.59566	2.879	5.5956602	8.5803283	73.151998	24.8895	969.3986327
7.4	5.72954	2.96	5.7295399	9.0333370	75.184001	25.48499	1020.579191

Table 36. Sample of Energy Absorption Obtained from Hydrocon Testing on Guardrail 3.C.4 (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kip)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
7.6	5.85227	3.04	5.8522701	9.4966089	77.215999	26.0309	1072.919284
7.8	5.97623	3.120	5.9762301	9.9697496	79.248002	26.58227	1126.374344
8	6.12498	3.2	6.12498	10.4537976	81.28	27.24391	1181.061691
8.2	6.22787	3.279	6.22787	10.9479111	83.311998	27.70157	1236.886239
8.4	6.37043	3.359	6.37043	11.4518426	85.343996	28.33567	1293.820017
8.6	6.49811	3.440	6.4981098	11.9665862	87.376004	28.90359	1351.975342
8.8	6.62703	3.520	6.6270299	12.4915913	89.408002	29.47703	1411.289994
9	6.76339	3.6	6.7633901	13.0272075	91.44	30.08356	1471.803492
9.2	6.87372	3.679	6.8737202	13.5726914	93.471998	30.57431	1533.431822
9.4	6.99024	3.759	6.9902401	14.1272493	95.503996	31.09259	1596.085325
9.6	7.1204	3.840	7.1204	14.6916771	97.536004	31.67154	1659.853934
9.8	7.21585	3.920	7.2158499	15.2651266	99.568002	32.0961	1724.641791
10	7.33238	4	7.3323798	15.8470552	101.6	32.61443	1790.387619
10.2	7.44518	4.079	7.4451799	16.438157	103.632	33.11616	1857.169827
10.4	7.54435	4.159	7.5443501	17.0377376	105.664	33.55727	1924.909964
10.6	7.66212	4.240	7.6621199	17.6459988	107.696	34.08111	1993.630831
10.8	7.77244	4.320	7.77244	18.2633806	109.728	34.57181	2063.382131
11	7.87037	4.4	7.8703699	18.8890923	111.76	35.00741	2134.074546
11.2	8.00301	4.479	8.0030098	19.5240269	113.792	35.59739	2205.808944
11.4	8.07119	4.559	8.0711899	20.1669942	115.824	35.90065	2278.45088
11.6	8.17904	4.640	8.17904	20.8170060	117.856	36.38037	2351.888693
11.8	8.28813	4.720	8.2881298	21.4756922	119.888	36.8656	2426.306525
12	8.37738	4.8	8.3773804	22.1423119	121.92	37.26259	2501.62069
12.2	8.50506	4.879	8.5050602	22.8176089	123.952	37.83051	2577.915199
12.4	8.57448	4.959	8.5744801	23.5007898	125.984	38.13929	2655.100434
12.6	8.66745	5.040	8.66745	24.1904697	128.016	38.55282	2733.019925
12.8	8.75051	5.120	8.7505102	24.8871875	130.048	38.92227	2811.734534
13	8.84348	5.2	8.8434801	25.5909464	132.08	39.3358	2891.244653
13.2	8.94389	5.279	8.9438896	26.3024404	134.112	39.78242	2971.628684
13.4	9.01207	5.359	9.0120697	27.0206781	136.144	40.08569	3052.7746
13.6	9.1038	5.440	9.1037998	27.7453158	138.176	40.4937	3134.643585
13.8	9.17818	5.520	9.1781797	28.4765942	140.208	40.82454	3217.262839
14	9.26247	5.6	9.2624702	29.2142195	142.24	41.19947	3300.599151
14.2	9.34305	5.679	9.34305	29.9584395	144.272	41.55789	3384.680538
14.4	9.42362	5.759	9.4236202	30.7091056	146.304	41.91626	3469.490189
14.6	9.51411	5.840	9.5141096	31.4666178	148.336	42.31876	3555.073314

Table 36. Sample of Energy Absorption Obtained from Hydrocon Testing on Guardrail 3.C.4 (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kip)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
14.8	9.58229	5.920	9.5822897	32.2304730	150.368	42.62202	3641.373064
15	9.66783	6	9.6678305	33.0004771	152.4	43.00251	3728.367504
15.2	9.72609	6.079	9.7260904	33.7762331	154.432	43.26165	3816.011803
15.4	9.80791	6.159	9.80791	34.5575924	156.464	43.62558	3904.289144
15.6	9.88228	6.240	9.8822803	35.3452031	158.496	43.95638	3993.272778
15.8	9.97649	6.320	9.97649	36.1395531	160.528	44.37543	4083.017808
16	10.0521	6.4	10.05211	36.9406963	162.56	44.71178	4173.530324
16.2	10.1042	6.480	10.10418	37.7469512	164.59201	44.94339	4264.620349
16.4	10.1773	6.559	10.17731	38.5582059	166.624	45.26867	4356.275261
16.6	10.2505	6.640	10.25045	39.3753196	168.656	45.594	4448.59211
16.8	10.3273	6.719	10.32731	40.1984250	170.68799	45.93587	4541.585905
17	10.4017	6.8	10.40169	41.0275883	172.72	46.26671	4635.26411
17.2	10.4662	6.880	10.46615	41.8623052	174.75201	46.55344	4729.569761
17.4	10.5219	6.959	10.52193	42.7018234	176.784	46.80154	4824.417851
17.6	10.5913	7.040	10.59135	43.5463579	178.816	47.11032	4919.832689
17.8	10.6719	7.119	10.67192	44.3968836	180.84799	47.4687	5015.924399
18	10.7029	7.2	10.70291	45.2518802	182.88	47.60655	5112.521234
18.2	10.7798	7.280	10.77977	46.1111909	184.91201	47.94842	5209.605464
18.4	10.8281	7.359	10.82812	46.9755013	186.944	48.16348	5307.254563
18.6	10.8851	7.440	10.88514	47.8440352	188.976	48.4171	5405.380828
18.8	10.957	7.519	10.95704	48.7177172	191.00799	48.73691	5504.088718
19	11.0103	7.6	11.01034	49.5964159	193.04	48.97399	5603.363393
19.2	11.0599	7.680	11.05993	50.4792302	195.07201	49.19457	5703.103048
19.4	11.1318	7.759	11.13182	51.3668948	197.104	49.51433	5803.390691
19.6	11.1839	7.840	11.18389	52.2595268	199.136	49.74594	5904.239537
19.8	11.2521	7.919	11.25207	53.1569599	201.16799	50.04921	6005.630804
20	11.2955	8	11.29545	54.0588643	203.2	50.24216	6107.527245
20.2	11.3475	8.080	11.34752	54.9645867	205.23201	50.47377	6209.85504
20.4	11.4033	8.159	11.4033	55.8746141	207.264	50.72188	6312.669202
20.6	11.4442	8.240	11.44421	56.7885181	209.296	50.90385	6415.921353
20.8	11.5074	8.319	11.50743	57.7065782	211.32799	51.18505	6519.643048
21	11.5421	8.4	11.54214	58.6285647	213.36	51.33944	6623.808345
21.2	11.6004	8.480	11.6004	59.5542700	215.39201	51.59858	6728.393789
21.4	11.6388	8.559	11.63883	60.4838337	217.424	51.76952	6833.415145
21.6	11.6884	8.640	11.68841	61.4169270	219.456	51.99005	6938.835283
21.8	11.7392	8.719	11.73924	62.3540273	221.48799	52.21614	7044.708131

Table 36. Sample of Energy Absorption Obtained from Hydrocon Testing on Guardrail 3.C.4 (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kip)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
22	11.7802	8.8	11.78015	63.2948067	223.52	52.39811	7150.996632
22.2	11.852	8.880	11.85205	64.2400985	225.55201	52.71792	7257.794942
22.4	11.8843	8.959	11.88428	65.1895460	227.584	52.86128	7365.062761
22.6	11.9215	9.040	11.92146	66.1417794	229.616	53.02665	7472.645332
22.8	11.9661	9.119	11.96609	67.0972757	231.64799	53.22517	7580.596537
23	12.0392	9.2	12.03923	68.0574924	233.68	53.5505	7689.081048
23.2	12.0801	9.280	12.08014	69.0222710	235.71201	53.73246	7798.08097
23.4	12.1062	9.359	12.10617	69.9897176	237.744	53.84824	7907.382312
23.6	12.1533	9.440	12.15327	70.9600991	239.776	54.05774	8017.015233
23.8	12.2066	9.519	12.20658	71.9344873	241.80799	54.29487	8127.100827
24	12.219	9.6	12.21897	72.9115132	243.84	54.34998	8237.484435
24.2	12.2971	9.680	12.29707	73.8921587	245.87201	54.69737	8348.276981
24.4	12.3107	9.759	12.31071	74.8764640	247.904	54.75804	8459.483003
24.6	12.359	9.840	12.35905	75.8632583	249.936	54.97305	8570.970238
24.8	12.3826	9.919	12.3826	76.8529184	251.96799	55.0778	8682.781238
25	12.4334	10	12.43343	77.8455635	254	55.3039	8794.929493
25.2	12.4657	10.08	12.46566	78.8415311	256.03201	55.44726	8907.453113
25.4	12.5041	10.16	12.50409	79.8403151	258.064	55.61819	9020.294933
25.6	12.545	10.24	12.545	80.8422827	260.096	55.80016	9133.496434
25.8	12.5636	10.32	12.56359	81.8466203	262.12799	55.88285	9246.96569
26	12.607	10.4	12.60698	82.8534471	264.16	56.07585	9360.716181
26.2	12.6293	10.48	12.62929	83.8629020	266.19201	56.17508	9474.76358
26.4	12.69	10.56	12.69003	84.8756687	268.224	56.44525	9589.185153
26.6	12.7086	10.64	12.70863	85.8916191	270.256	56.52798	9703.966422
26.8	12.7433	10.72	12.74333	86.9096914	272.28799	56.68233	9818.987414
27	12.7545	10.8	12.75449	87.9296083	274.32	56.73197	9934.216806
27.2	12.8189	10.88	12.81895	88.9525500	276.35201	57.01869	10049.78794
27.4	12.8289	10.96	12.82887	89.9784566	278.384	57.06281	10165.69405
27.6	12.871	11.04	12.87102	91.0064563	280.416	57.2503	10281.83663
27.8	12.9057	11.12	12.90573	92.0375201	282.44799	57.40469	10398.3254
28	12.9293	11.2	12.92928	93.0709247	284.48	57.50944	10515.07862
28.2	12.959	11.28	12.95903	94.1064613	286.51201	57.64177	10632.07271
28.4	12.9987	11.36	12.9987	95.1447642	288.544	57.81822	10749.37935
28.6	13.0148	11.44	13.01481	96.1853088	290.576	57.88987	10866.93924
28.8	13.052	11.52	13.052	97.2279749	292.60799	58.0553	10984.73883
29	13.083	11.6	13.08299	98.2733787	294.64	58.19314	11102.84771

Table 36. Sample of Energy Absorption Obtained from Hydrocon Testing on Guardrail 3.C.4 (Continued).

Time (sec)	Load (kips)	Displ. (in)	Load (kip)	Energy (kip-in)	Displ. (mm)	Load (kN)	Energy (kN-mm)
29.2	13.1065	11.68	13.10654	99.3209641	296.67201	58.29789	11221.20307
29.4	13.1475	11.76	13.14745	100.3711174	298.704	58.47986	11339.84855
29.6	13.1809	11.84	13.18092	101.4242564	300.736	58.62873	11458.83135
29.8	13.2032	11.92	13.20324	102.4796165	302.76799	58.72801	11578.06509
30	13.2119	12	13.21191	103.5362267	304.8	58.76658	11697.44007

Note: Maximum values are highlighted.

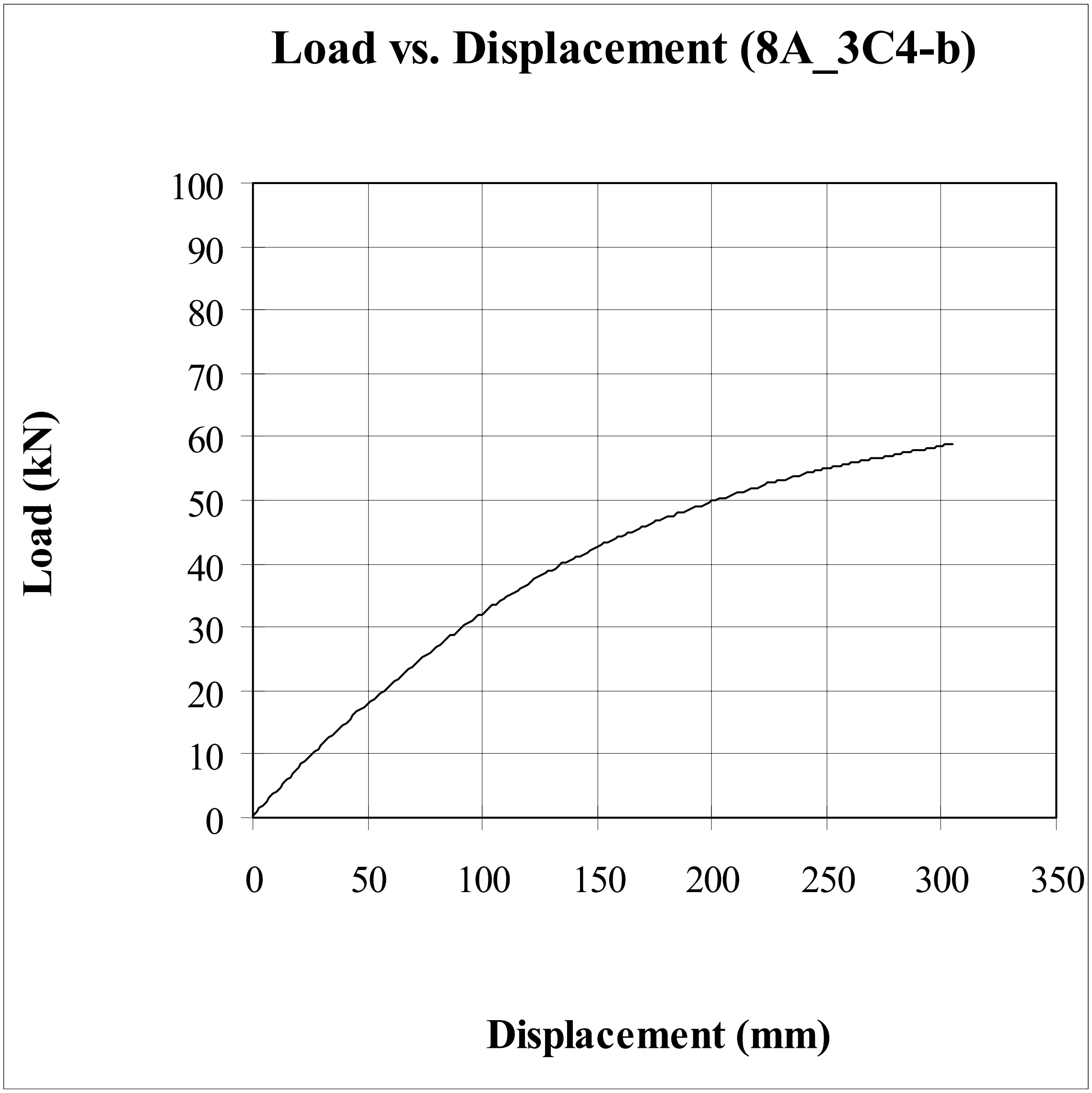

Figure 52. Sample of Load vs. Displacement for Testing Done on Guardrail 3.C.4.

Table 37. Sample of Pendulum Testing on 6 ft Guardrail.

Pendulum Test 414586-P13
Max 10 ms force = 13.59 kips

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
0	28.689	0		
0.001154	28.690154	0.020083		-0.0024881
0.0046158	28.693616	0.037298		-0.0099531
0.0103856	28.699386	0.057385		-0.0223968
0.0150014	28.704001	0.077477		-0.0323535
0.0167324	28.705732	0.09757		-0.0360877
0.0159905	28.704991	0.114793		-0.0344873
0.0142596	28.70326	0.134886	2.6288791	-0.0307532
0.0131056	28.702106	0.154978	4.1310958	-0.0282639
0.0123638	28.701364	0.172199	5.4164975	-0.0266637
0.0100559	28.699056	0.192289	6.3728056	-0.0216856
0.0048631	28.693863	0.212377	7.147144	-0.0104864
-0.006965	28.682035	0.232458	7.9059956	0.0150155
-0.036638	28.652362	0.249659	8.6996925	0.0789461
-0.125493	28.563507	0.269684	9.474031	0.2699869
-0.287624	28.401376	0.289622	10.128347	0.6170452
-0.499086	28.189914	0.309429	10.701357	1.0667343
-0.676136	28.012864	0.32629	11.313085	1.4406579
-0.839132	27.849868	0.345842	12.00999	1.7828181
-0.962317	27.726683	0.365293	12.706894	2.0400817
-1.056282	27.632718	0.381901	13.29152	2.2355548
-1.170235	27.518765	0.401204	13.58964	2.4717185
-1.287939	27.401061	0.420426	13.4309	2.7146301
-1.396122	27.292878	0.439569	12.923709	2.9369761
-1.475498	27.213502	0.455921	12.42426	3.0995551
-1.564641	27.124359	0.474939	12.199702	3.2815754
-1.664458	27.024542	0.493891	12.250035	3.4846823
-1.757929	26.931071	0.510078	12.381672	3.6741959
-1.865247	26.823753	0.528892	12.443619	3.890976
-1.965641	26.723359	0.547634	12.404903	4.0929866
-2.064881	26.624119	0.566305	12.311982	4.2919307
-2.161319	26.527681	0.582251	12.145499	4.4845477
-2.297774	26.391226	0.600772	11.746715	4.7558984
-2.450385	26.238615	0.619193	11.057554	5.0577174
-2.578969	26.110031	0.634897	10.252242	5.3106594
-2.715713	25.973287	0.653127	9.5204919	5.5782901
-2.839763	25.849237	0.671265	8.8623042	5.8198617
-2.955447	25.733553	0.689318	8.2002449	6.0440991
-3.047928	25.641072	0.704731	7.4723667	6.2226378
-3.136783	25.552217	0.722649	6.6167226	6.3935696
-3.187269	25.501731	0.740517	5.6255694	6.4904255

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-3.195346	25.493654	0.758366	4.6034426	6.5059047
-3.185455	25.503545	0.773665	3.6316478	6.4869499
-3.179974	25.509026	0.791519	2.7411584	6.4764427
-3.183724	25.505276	0.809374	1.9203596	6.4836321
-3.185455	25.503545	0.824677	1.1382777	6.4869499
-3.181128	25.507872	0.842531	0.4142712	6.4786549
-3.175647	25.513353	0.860388	-0.1161507	6.4681459
-3.174493	25.514507	0.878248	-0.3329656	6.4659331
-3.176718	25.512282	0.893556	-0.3058637	6.4702004
-3.178161	25.510839	0.911414	-0.2594034	6.4729661
-3.176141	25.512859	0.929273	-0.3136071	6.4690941
-3.173174	25.515826	0.944581	-0.3987843	6.4634042
-3.169423	25.519577	0.962444	-0.4258862	6.4562118
-3.165096	25.523904	0.980309	-0.4181428	6.4479116
-3.16048	25.52852	0.998177	-0.4336296	6.4390564
-3.156029	25.532971	1.013496	-0.4607314	6.430516
-3.149971	25.539029	1.031371	-0.4646031	6.4188892
-3.143913	25.545087	1.04925	-0.441373	6.4072596
-3.13872	25.55028	1.064579	-0.3987843	6.3972892
-3.132085	25.556915	1.082466	-0.3484523	6.3845463
-3.125738	25.563262	1.100358	-0.3097354	6.3723543
-3.119968	25.569032	1.118255	-0.2710185	6.3612681
-3.114775	25.574225	1.133598	-0.1780979	6.3512883
-3.110448	25.578552	1.151501	-0.0580754	6.3429703
-3.110737	25.578263	1.169406	0.0116151	6.3435249
-3.113621	25.575379	1.18731	0.050332	6.3490703
-3.116094	25.572906	1.202654	0.1122791	6.3538231
-3.119556	25.569444	1.220554	0.1742261	6.3604761
-3.122441	25.566559	1.238452	0.201328	6.3660196
-3.123677	25.565323	1.253791	0.1897129	6.3683952
-3.12887	25.56013	1.271685	0.1548677	6.3783715
-3.139544	25.549456	1.289574	0.1122791	6.398872
-3.147622	25.541378	1.307455	0.0774339	6.4143801
-3.149353	25.539647	1.32278	0.0542037	6.4177026
-3.150795	25.538205	1.340657	0.0193585	6.4204712
-3.153392	25.535608	1.358533	-0.0154868	6.4254543
-3.153639	25.535361	1.373854	-0.0271018	6.4259289
-3.149023	25.539977	1.39173	-0.0425886	6.4170698
-3.139503	25.549497	1.409612	-0.1238941	6.3987928
-3.129406	25.559594	1.4275	-0.2323015	6.3794007
-3.124708	25.564292	1.442837	-0.2903769	6.3703748
-3.123265	25.565735	1.460733	-0.3290938	6.3676034
-3.121823	25.567177	1.478629	-0.3832975	6.3648318
-3.120339	25.568661	1.49397	-0.4336295	6.3619809

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-3.119762	25.569238	1.511868	-0.4646031	6.3608721
-3.119185	25.569815	1.529767	-0.4452446	6.3597633
-3.117166	25.571834	1.547666	-0.3794259	6.3558825
-3.114198	25.574802	1.56301	-0.3252222	6.3501794
-3.109871	25.579129	1.580914	-0.3174788	6.3418612
-3.104678	25.584322	1.598821	-0.3368372	6.3318775
-3.099197	25.589803	1.616732	-0.3678108	6.3213369
-3.094746	25.594254	1.632088	-0.4103994	6.312776
-3.088976	25.600024	1.650006	-0.452988	6.3016764
-3.083495	25.605505	1.667928	-0.4994483	6.2911293
-3.080775	25.608225	1.683292	-0.5304218	6.2858947
-3.079621	25.609379	1.701218	-0.5381652	6.2836737
-3.078755	25.610245	1.719145	-0.5459086	6.2820079
-3.076448	25.612552	1.737073	-0.5497803	6.2775656
-3.071997	25.617003	1.752442	-0.5381652	6.2689971
-3.064784	25.624216	1.770376	-0.5265501	6.2551098
-3.057861	25.631139	1.788315	-0.5226785	6.2417743
-3.051679	25.637321	1.803696	-0.5226785	6.2298645
-3.043889	25.645111	1.821645	-0.5420369	6.2148542
-3.037543	25.651457	1.839599	-0.5691387	6.2026201
-3.032061	25.656939	1.857556	-0.5807538	6.1920519
-3.026869	25.662131	1.872952	-0.5691387	6.1820379
-3.021964	25.667036	1.890917	-0.5304218	6.1725783
-3.018502	25.670498	1.908886	-0.4878332	6.1658998
-3.014546	25.674454	1.924289	-0.4607314	6.1582662
-3.009353	25.679647	1.942263	-0.4220145	6.1482453
-3.004737	25.684263	1.96024	-0.3832975	6.1393362
-3.000122	25.688878	1.978221	-0.3678108	6.1304254
-2.996907	25.692093	1.993635	-0.3484523	6.1242188
-2.994599	25.694401	2.01162	-0.3174788	6.1197622
-2.993157	25.695843	2.029607	-0.3097354	6.1169767
-2.992003	25.696997	2.047595	-0.301992	6.1147481
-2.990519	25.698481	2.063013	-0.2787618	6.1118827
-2.988211	25.700789	2.081003	-0.2594034	6.1074251
-2.986192	25.702808	2.098994	-0.2361732	6.1035243
-2.984213	25.704787	2.114416	-0.2129431	6.0997028
-2.981329	25.707671	2.132411	-0.2051997	6.0941293
-2.979021	25.709979	2.150407	-0.201328	6.0896701
-2.977001	25.711999	2.168405	-0.2051997	6.0857679
-2.975023	25.713977	2.183833	-0.2090714	6.0819451
-2.972715	25.716285	2.201833	-0.2051997	6.0774848
-2.970696	25.718304	2.219835	-0.2090714	6.0735816
-2.969459	25.719541	2.235267	-0.2129431	6.0711918
-2.968305	25.720695	2.253271	-0.1974563	6.0689612

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-2.966863	25.722137	2.271276	-0.1742262	6.0661728
-2.96542	25.72358	2.289282	-0.1626111	6.0633843
-2.964184	25.724816	2.304716	-0.1471243	6.060994
-2.962453	25.726547	2.322724	-0.1355092	6.0576474
-2.960722	25.728278	2.340733	-0.1355092	6.0543005
-2.958744	25.730256	2.356171	-0.1316375	6.0504753
-2.956148	25.732852	2.374183	-0.1277659	6.0454542
-2.954705	25.734295	2.392196	-0.1316375	6.0426645
-2.954705	25.734295	2.41021	-0.1161508	6.0426645
-2.954952	25.734048	2.425651	-0.0813055	6.0431427
-2.954952	25.734048	2.443665	-0.0387169	6.0431427
-2.954664	25.734336	2.461679	-0.0077434	6.0425848
-2.953221	25.735779	2.479693	0.0232301	6.0397949
-2.951738	25.737262	2.495135	0.0580754	6.0369251
-2.950872	25.738128	2.513152	0.0851772	6.035251
-2.949718	25.739282	2.531169	0.0967923	6.0330188
-2.949224	25.739776	2.546612	0.0929206	6.0320621
-2.951532	25.737468	2.564629	0.0967923	6.0365266
-2.955859	25.733141	2.582644	0.1045357	6.0448962
-2.959609	25.729391	2.600656	0.1238942	6.0521488
-2.962082	25.726918	2.616093	0.1703545	6.0569302
-2.964679	25.724321	2.634101	0.2168148	6.0619501
-2.966698	25.722302	2.652107	0.25166	6.0658542
-2.967934	25.721066	2.66754	0.2903769	6.0682442
-2.968511	25.720489	2.685545	0.3058637	6.0693596
-2.9688	25.7202	2.703549	0.2981203	6.0699172
-2.969665	25.719335	2.721553	0.2826335	6.0715901
-2.971149	25.717851	2.736984	0.2671468	6.0744579
-2.974611	25.714389	2.754985	0.2477883	6.0811486
-2.979804	25.709196	2.772984	0.2439166	6.0911831
-2.984255	25.704745	2.788408	0.2594034	6.0997824
-2.988582	25.700418	2.8064	0.2942486	6.1081415
-2.992044	25.696956	2.824389	0.3407089	6.1148277
-2.994929	25.694071	2.842375	0.3716825	6.1203989
-2.997154	25.691846	2.857791	0.402656	6.1246962
-2.998597	25.690403	2.875775	0.4413729	6.1274813
-2.998885	25.690115	2.893758	0.4491163	6.1280383
-2.999751	25.689249	2.911741	0.4297579	6.1297093
-3.002223	25.686777	2.927154	0.4181428	6.1344832
-3.007416	25.681584	2.945133	0.3987843	6.1445069
-3.014051	25.674949	2.963107	0.3832976	6.157312
-3.019244	25.669756	2.978511	0.3794259	6.167331
-3.024726	25.664274	2.996478	0.3832976	6.1779045
-3.031649	25.657351	3.01444	0.3987843	6.1912572

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-3.038573	25.650427	3.032398	0.4297578	6.2046064
-3.042282	25.646718	3.047787	0.4568597	6.2117562
-3.045167	25.643833	3.065739	0.4684748	6.2173165
-3.047187	25.641813	3.083689	0.4607314	6.2212083
-3.047928	25.641072	3.099074	0.4452446	6.2226379
-3.049371	25.639629	3.117022	0.4491163	6.2254175
-3.051967	25.637033	3.134969	0.4607314	6.2304204
-3.054852	25.634148	3.152914	0.4413729	6.2359786
-3.058067	25.630933	3.168293	0.4336295	6.2421712
-3.063259	25.625741	3.186233	0.4568597	6.2521731
-3.069029	25.619971	3.204169	0.4839615	6.2632839
-3.073728	25.615272	3.21954	0.5226785	6.2723295
-3.078632	25.610368	3.237469	0.5691388	6.28177
-3.083825	25.605175	3.255394	0.6001123	6.2917638
-3.09046	25.59854	3.273315	0.6233425	6.3045308
-3.0959	25.5931	3.288673	0.6465726	6.3149957
-3.100804	25.588196	3.306586	0.654316	6.324428
-3.106286	25.582714	3.324496	0.6504443	6.3349679
-3.112921	25.576079	3.342402	0.6388292	6.3477237
-3.118855	25.570145	3.357746	0.6272141	6.3591298
-3.126068	25.562932	3.375642	0.6117274	6.3729878
-3.13328	25.55572	3.393534	0.5807538	6.3868419
-3.138967	25.550033	3.408865	0.5420369	6.3977641
-3.145314	25.543686	3.426748	0.5342935	6.4099497
-3.151372	25.537628	3.444627	0.5342935	6.4215787
-3.156854	25.532146	3.462501	0.5071917	6.4320977
-3.16081	25.52819	3.477819	0.452988	6.439689
-3.16456	25.52444	3.495688	0.3987843	6.4468838
-3.167445	25.521555	3.513554	0.3678108	6.4524176
-3.168929	25.520071	3.528866	0.3639391	6.4552633
-3.170371	25.518629	3.54673	0.3561957	6.4580298
-3.173256	25.515744	3.564592	0.3484523	6.4635623
-3.177584	25.511416	3.582451	0.3678108	6.4718598
-3.180551	25.508449	3.597757	0.3949126	6.4775488
-3.181128	25.507872	3.615613	0.4142711	6.4786549
-3.179974	25.509026	3.633469	0.4297579	6.4764427
-3.180716	25.508284	3.648774	0.452988	6.4778648
-3.185332	25.503668	3.666628	0.4762182	6.486713
-3.191101	25.497899	3.684479	0.4800899	6.4977708
-3.196294	25.492706	3.702326	0.4607314	6.5077208
-3.202229	25.486771	3.717619	0.452988	6.5190897
-3.211172	25.477828	3.735457	0.4800899	6.536217
-3.21925	25.46975	3.753289	0.5304219	6.5516817
-3.225596	25.463404	3.771115	0.5768822	6.5638291

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-3.230542	25.458458	3.786392	0.603984	6.5732924
-3.235735	25.453265	3.804211	0.6155991	6.583227
-3.239197	25.449803	3.822027	0.6233425	6.5898489
-3.24068	25.44832	3.837296	0.6155991	6.5926866
-3.242988	25.446012	3.855109	0.5691388	6.5971005
-3.247892	25.441108	3.87292	0.5188068	6.6064786
-3.254239	25.434761	3.890726	0.4994483	6.6186123
-3.259432	25.429568	3.905986	0.5110634	6.6285376
-3.265779	25.423221	3.923784	0.5265501	6.6406658
-3.27328	25.41572	3.941578	0.5381652	6.6549953
-3.279461	25.409539	3.956825	0.5575237	6.666802
-3.284654	25.404346	3.97461	0.5846255	6.6767175
-3.287539	25.401461	3.992392	0.5923689	6.6822252
-3.28927	25.39973	4.010173	0.5691388	6.6855296
-3.291743	25.397257	4.025412	0.5459086	6.6902497
-3.297513	25.391487	4.043188	0.5265501	6.7012614
-3.305302	25.383698	4.060959	0.5110634	6.7161233
-3.311484	25.377516	4.076188	0.4994483	6.7279152
-3.317254	25.371746	4.09395	0.5110634	6.7389184
-3.322446	25.366554	4.111708	0.5459086	6.7488191
-3.327351	25.361649	4.129463	0.5962406	6.758168
-3.330565	25.358435	4.144679	0.6310858	6.7642948
-3.33345	25.35555	4.162429	0.6388292	6.7697926
-3.336335	25.352665	4.180177	0.6233425	6.7752897
-3.340085	25.348915	4.197922	0.5962406	6.7824351
-3.344784	25.344216	4.21313	0.5768822	6.7913849
-3.351996	25.337004	4.230869	0.5730105	6.8051204
-3.36065	25.32835	4.248602	0.6814179	6.8215979
-3.368563	25.320437	4.263796	1.1498927	6.8366581
-3.376641	25.312359	4.281518	2.1371742	6.8520273
-3.382699	25.306301	4.299234	3.3180405	6.8635509
-3.387892	25.301108	4.316947	4.1620695	6.8734261
-3.391849	25.297151	4.332126	4.48342	6.8809487
-3.395599	25.293401	4.349833	4.4137295	6.8880784
-3.399638	25.289362	4.367537	4.1969147	6.8957553
-3.410765	25.278235	4.382707	4.1039941	6.9168998
-3.458654	25.230346	4.400385	4.1852996	7.0077932
-3.570877	25.118123	4.418007	4.2588618	7.2201151
-3.735315	24.953685	4.435532	4.2201448	7.5295198
-3.867114	24.821886	4.450465	4.1581977	7.7760418
-3.957699	24.731301	4.467809	4.1736845	7.9447204
-3.981932	24.707068	4.485112	4.2162731	7.9897401
-3.969816	24.719184	4.49994	4.204658	7.9672358
-3.955391	24.733609	4.517249	4.0730205	7.9404305

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-3.963758	24.725242	4.534559	3.6316475	7.9559795
-3.983375	24.705625	4.55186	2.6753395	7.9924184
-3.990793	24.698207	4.566681	1.4789865	8.0061903
-3.988485	24.700515	4.583971	0.6427009	8.0019062
-3.989639	24.699361	4.601261	0.3523239	8.0040483
-3.997717	24.691283	4.618547	0.4065276	8.0190404
-4.003157	24.685843	4.63336	0.5575237	8.0291343
-4.005465	24.683535	4.65064	0.6117274	8.0334159
-4.010658	24.678342	4.667916	0.5110634	8.0430481
-4.017581	24.671419	4.682721	0.3910409	8.0558878
-4.02162	24.66738	4.69999	0.3949126	8.0633759
-4.023928	24.665072	4.717256	0.4646031	8.0676543
-4.030563	24.658437	4.73452	0.452988	8.0799525
-4.036251	24.652749	4.749313	0.3832975	8.0904912
-4.037405	24.651595	4.766569	0.3949126	8.0926292
-4.03827	24.65073	4.783825	0.4413729	8.0942326
-4.042474	24.646526	4.798614	0.4065277	8.1020198
-4.045647	24.643353	4.815866	0.3639391	8.1078976
-4.045647	24.643353	4.833116	0.4103994	8.1078976
-4.048821	24.640179	4.850365	0.4413729	8.1137745
-4.053519	24.635481	4.865148	0.3949126	8.1224741
-4.055538	24.633462	4.882392	0.3832975	8.1262129
-4.057558	24.631442	4.899635	0.452988	8.1299513
-4.063245	24.625755	4.914412	0.4800898	8.1404785
-4.069303	24.619697	4.931648	0.4375012	8.1516895
-4.071611	24.617389	4.948881	0.4297578	8.1559596
-4.075939	24.613061	4.966112	0.452988	8.163965
-4.082862	24.606138	4.980877	0.4258862	8.1767708
-4.088344	24.600656	4.9981	0.3871692	8.1869061
-4.090652	24.598348	5.015319	0.4103994	8.1911729
-4.096133	24.592867	5.032536	0.4258862	8.201305
-4.103057	24.585943	5.04729	0.3987843	8.2141002
-4.106807	24.582193	5.064499	0.402656	8.2210295
-4.10623	24.58277	5.081707	0.452988	8.2199635
-4.107219	24.581781	5.096456	0.452988	8.2217909
-4.110104	24.578896	5.113662	0.4103994	8.2271203
-4.110681	24.578319	5.130867	0.4142711	8.2281861
-4.111546	24.577454	5.148072	0.4413729	8.2297847
-4.11575	24.57325	5.162817	0.4181428	8.2375488
-4.12152	24.56748	5.180016	0.3794259	8.2482033
-4.125847	24.563153	5.197212	0.402656	8.2561924
-4.131287	24.557713	5.211948	0.452988	8.266234
-4.139365	24.549635	5.229136	0.4646031	8.2811401
-4.144269	24.544731	5.246319	0.4762182	8.2901878

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-4.146866	24.542134	5.263499	0.5265501	8.294977
-4.150822	24.538178	5.278223	0.5497803	8.3022739
-4.156592	24.532408	5.295398	0.5188068	8.3129132
-4.160054	24.528946	5.312569	0.5071917	8.3192955
-4.162279	24.526721	5.327286	0.5188068	8.323398
-4.167184	24.521816	5.344453	0.4955766	8.3324372
-4.172953	24.516047	5.361616	0.4723465	8.3430694
-4.177569	24.511431	5.378776	0.4917049	8.3515733
-4.18202	24.50698	5.393482	0.5188068	8.359772
-4.188367	24.500633	5.410634	0.50332	8.3714601
-4.192694	24.496306	5.427783	0.4839616	8.3794275
-4.195291	24.493709	5.44493	0.50332	8.3842073
-4.199	24.49	5.459625	0.5265502	8.3910347
-4.204481	24.484519	5.476766	0.5188068	8.4011222
-4.209097	24.479903	5.493903	0.5071917	8.4096152
-4.213053	24.475947	5.50859	0.5110634	8.4168936
-4.219112	24.469888	5.525721	0.4994483	8.4280364
-4.224593	24.464407	5.542848	0.4723465	8.4381156
-4.227766	24.461234	5.559972	0.4762182	8.4439499
-4.230734	24.458266	5.574648	0.4955766	8.4494046
-4.236503	24.452497	5.591767	0.50332	8.4600092
-4.242562	24.446438	5.608881	0.5110634	8.4711413
-4.246271	24.442729	5.623548	0.5226785	8.4779555
-4.25031	24.43869	5.640657	0.5420369	8.4853743
-4.254925	24.434075	5.657762	0.5459086	8.4938513
-4.258387	24.430613	5.674865	0.553652	8.5002081
-4.260613	24.428387	5.689522	0.5730105	8.5042941
-4.26494	24.42406	5.706621	0.5846255	8.5122381
-4.271287	24.417713	5.723715	0.5730105	8.5238866
-4.276974	24.412026	5.738364	0.5613954	8.5343224
-4.283033	24.405967	5.755451	0.5652671	8.5454361
-4.289956	24.399044	5.772532	0.5730105	8.5581341
-4.297745	24.391255	5.789609	0.5768822	8.572415
-4.303186	24.385814	5.804242	0.5923689	8.5823862
-4.308378	24.380622	5.82131	0.6155991	8.5919022
-4.314148	24.374852	5.838375	0.6155991	8.6024731
-4.319918	24.369082	5.855435	0.5923689	8.6130415
-4.323627	24.365373	5.870056	0.5730105	8.6198342
-4.327377	24.361623	5.88711	0.5691388	8.6267012
-4.332282	24.356718	5.904161	0.553652	8.6356797
-4.33698	24.35202	5.918774	0.5304219	8.6442792
-4.341884	24.347116	5.935819	0.5226785	8.6532541
-4.347366	24.341634	5.95286	0.5226785	8.6632827
-4.353424	24.335576	5.969897	0.5188068	8.6743643

Table 37. Sample of Pendulum Testing on 6 ft. Guardrail (Continued).

Change in Vel. (ft/s)	Pendulum Vel. (ft/s)	Displacement (ft)	10 ms avg force (kips)	Energy (Kip ft)
-4.35738	24.33162	5.984497	0.5188068	8.6815998
-4.360842	24.328158	6.001528	0.5342936	8.6879299
-4.365169	24.323831	6.018556	0.5497803	8.6958412
-4.369868	24.319132	6.033149	0.5497803	8.7044291
-4.374772	24.314228	6.050171	0.5575237	8.7133919
-4.378811	24.310189	6.067189	0.5807539	8.7207716
-4.383427	24.305573	6.084205	0.5884973	8.7292041
-4.388125	24.300875	6.098787	0.5884973	8.7377856
-4.393606	24.295394	6.115795	0.6078557	8.7477951
-4.399088	24.289912	6.1328	0.642701	8.7578024
-4.40428	24.28472	6.147373	0.6581877	8.767281
-4.410339	24.278661	6.16437	0.6581877	8.7783367
-4.416397	24.272603	6.181363	0.6698028	8.7893897
-4.423609	24.265391	6.198351	0.6852896	8.8025443
-4.430286	24.258714	6.212908	0.6814179	8.8147183
-4.436921	24.252079	6.229887	0.6698028	8.8268139
-4.442979	24.246021	6.246861	0.677288	8.8378547
-4.45048	24.23852	6.263831	0.6814178	8.8515206
-4.457404	24.231596	6.278372	0.6814178	8.8641314
-4.464039	24.224961	6.295332	0.6865801	8.8762134
-4.469809	24.219191	6.312287	0.6870494	8.8867168
-4.475001	24.213999	6.326817	0.6690284	8.8961678
-4.480483	24.208517	6.343765	0.6538858	8.9061415
-4.48481	24.20419	6.36071	0.6581877	8.914014

Note: Maximum values are highlighted.

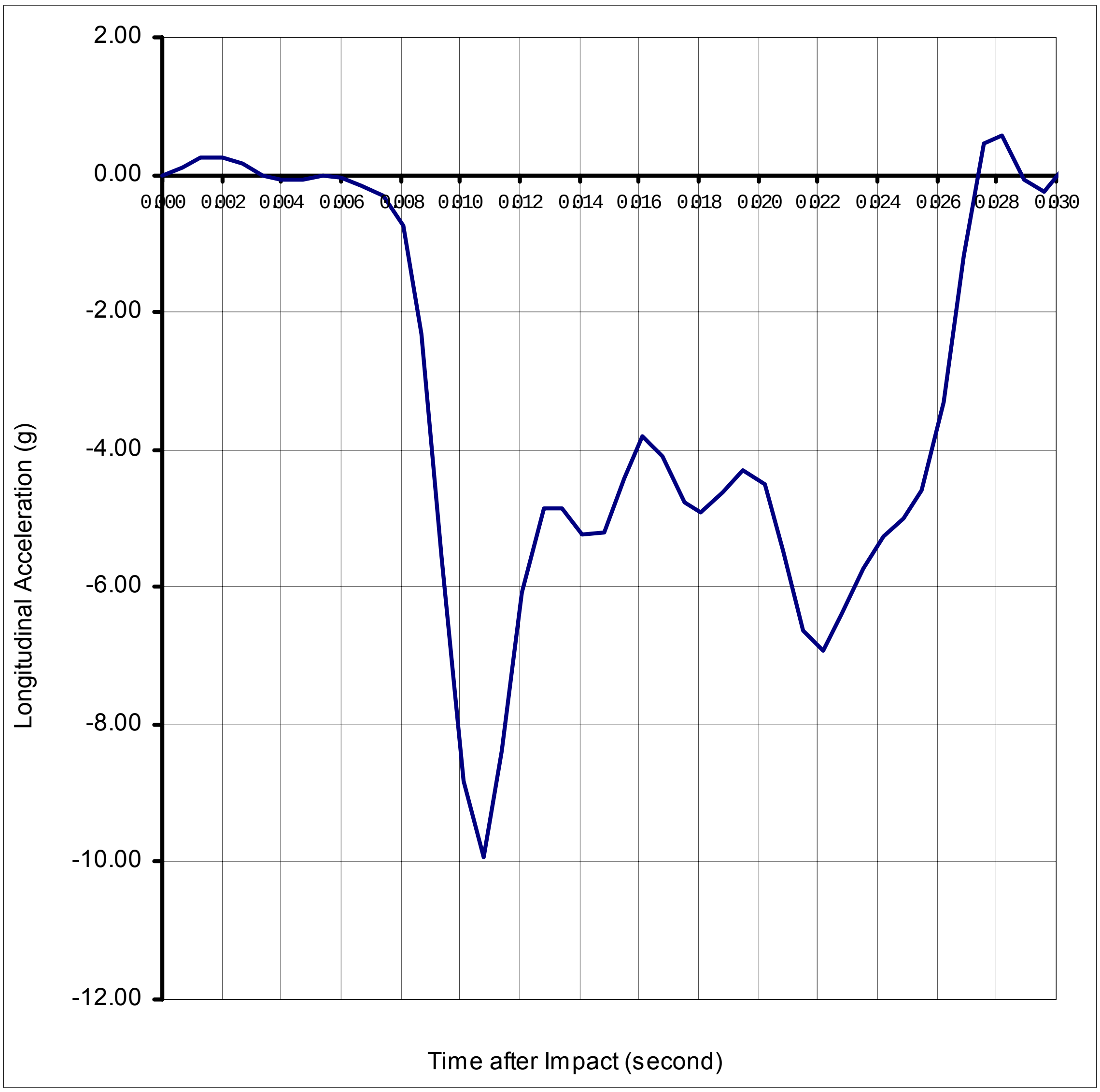

Figure 53. Sample of Pendulum Testing on 6 ft Guardrail.

Table 38. Sample Data from Flexural Creep Test on Guardrail.

		Real Data			Projected Data		
Time		A					
		Deflection	Strain	% Strain	Deflection	% Strain	% Variation
hour	min. / hr.	(in.)		(%)	(in.)	(%)	(%)
0.00	Initial Reading	0.000	0.00000	0.0000	0.000000	0.000	
0.02	1	0.152	0.00079	0.0794	0.150303	0.079	1.1%
0.10	6	0.171	0.00089	0.0894	0.171152	0.089	0.1%
0.20	12	0.179	0.00094	0.0936	0.179973	0.094	0.5%
0.50	30	0.191	0.00100	0.0998	0.192335	0.101	0.7%
1	1	0.202	0.00106	0.1056	0.202247	0.106	0.1%
2	2	0.212	0.00111	0.1108	0.212671	0.111	0.3%
5	5	0.226	0.00118	0.1181	0.227278	0.119	0.6%
20	20	0.248	0.00130	0.1296	0.251309	0.131	1.3%
50	50	0.272	0.00142	0.1422	0.268570	0.140	1.3%
100	100	0.294	0.00154	0.1537	0.282412	0.148	3.9%
150	150	0.285	0.00149	0.1489	0.290837	0.152	2.0%
200	200	0.295	0.00154	0.1542	0.296967	0.155	0.7%
240	240	0.300	0.00157	0.1568	0.300918	0.157	0.3%
360	360				0.309895	0.162	
500	500				0.317364	0.166	
620	620				0.322353	0.168	
700	700				0.325201	0.170	
800	800				0.328365	0.172	
1000	1000				0.333720	0.174	
1 Hr. Recovery		0.169	0.00088	0.0883	Percent Recovered (%)		43.67%

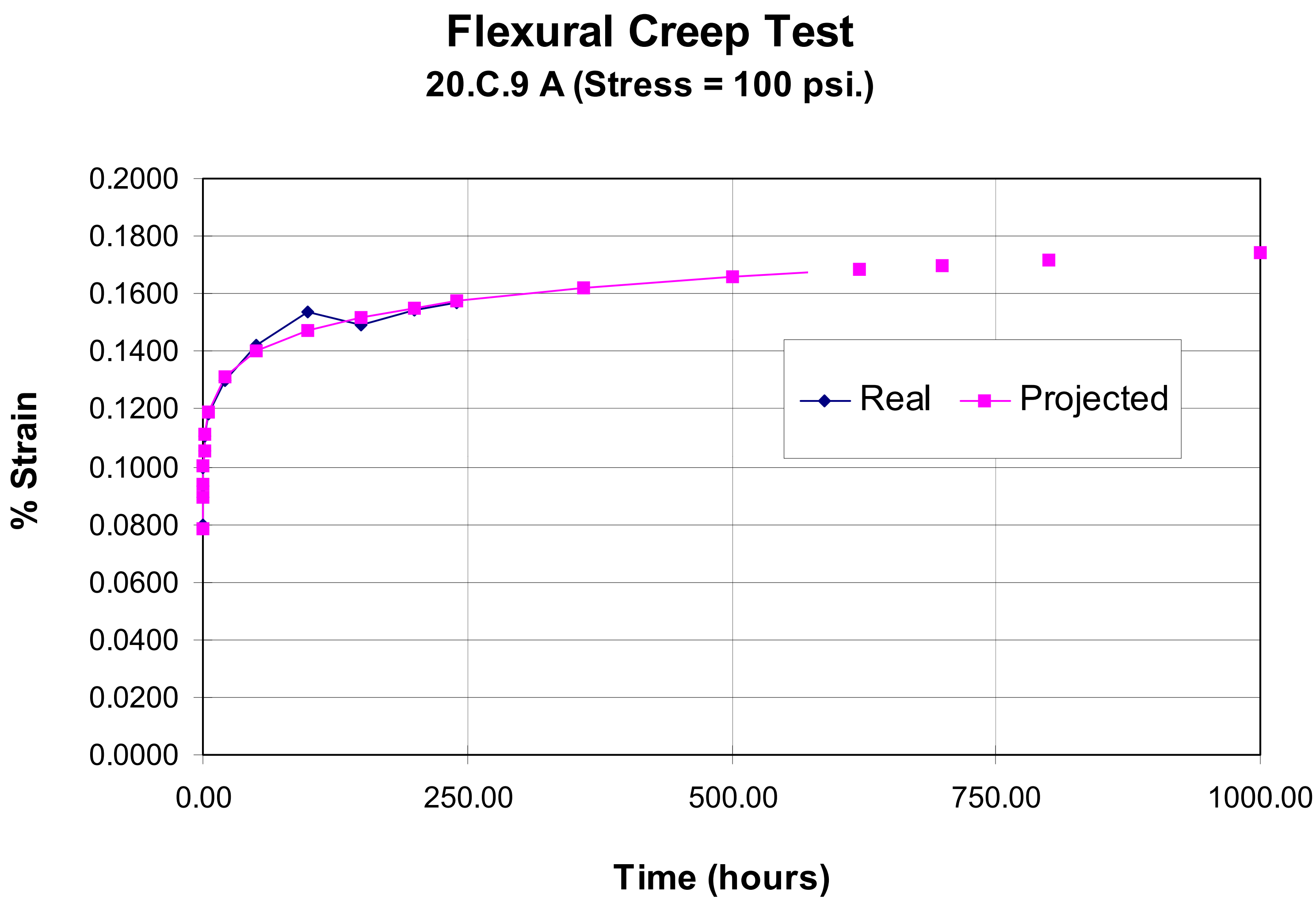

Figure 54. Sample Curve Obtained from Flexural Creep Test on Guardrail.

Table 39. Sample of Deflection Measurements.

Date 1996	Day	B West (mm)	C South (mm)	Deflect. N / S (mm)	Deflect. E / W (mm)	A No. (mm)	B West (mm)	C Sou. (mm)	Deflect. N / S (mm)	Deflect. E / W (mm)	A North (mm)	B West (mm)	D East (mm)	Deflect. N / S (mm)	Deflect. E / W (mm)	Deflect. N / S (mm)	Stand. Devia. (+/-)	High (mm)	Low (mm)	Deflect. E / W (mm)
10/4		11	9	0	0		3	5	0	0	21		6	0	0	0	0	0	0	0
10/7	3	10	3	-6	-1		7	2	-3	4	27		3	-6	3	-5.00	1.73	-3.27	-6.73	2.00
10/8	4	10	7	-2	-1		10	2	-3	7	27		2	-6	4	-3.67	2.08	-1.59	-5.75	3
10/9	5	10	8	-1	-1		13	3	-2	10	30		2	-9	4	-4	4.36	0.36	-8.36	4.33
10/10	6	20	18	9	9		15	8	3	12	35	17		-14	23	-0.67	11.93	11.26	-12.60	14.67
10/11	7	12	8	-1	1	5	23		-10	20	32	7		-11	13	-7.33	5.51	-1.83	-12.84	11.33
10/14	10	15	5	-4	4	7	33		-12	30	35	8		-14	14	-10.00	5.29	-4.71	-15.29	16.00
10/15	11	19	9	0	8	9	32		-14	29	34	9		-13	15	-9.00	7.81	-1.19	-16.81	17.33
10/28	24	12	11	2	1		32	5	0	29	29	7		-8	13	-2.00	5.29	3.29	-7.29	14.33
10/29	25	20	19	10	9		32	6	1	29	40	7		-19	13	-3	14.84	12.18	-17.51	17.00
10/31	27	15	12	3	4		40	5	0	37	35	11		-14	17	-3.67	9.07	5.41	-12.74	19
11/5	32	26	17	8	15		55	10	5	52	50	20		-29	26	-5	20.55	15.22	-25.88	31.00
11/12	39	10	13	4	-1		34	7	2	31	50	15		-29	21	-7.67	18.50	10.84	-26.17	17.00
11/21	48	12	10	1	1	5	36		-10	33	46	20		-25	26	-11.33	13.05	1.72	-24.38	20
11/26	53	11	10	1	0		25	3	-2	22	41	11		-20	17	-7.00	11.36	4.36	-18.36	13.00
12/3	60	15	16	7	4		39	1	-4	36	41	8		-20	14	-5.67	13.58	7.91	-19.24	18
12/12	69	19	16	7	8	8	50		-13	47	47	13		-26	19	-10.67	16.62	5.96	-27.29	24.67
12/18	75	10	10	1	-1		46	3	-2	43	48	16		-27	22	-9	15.37	6.04	-24.71	21

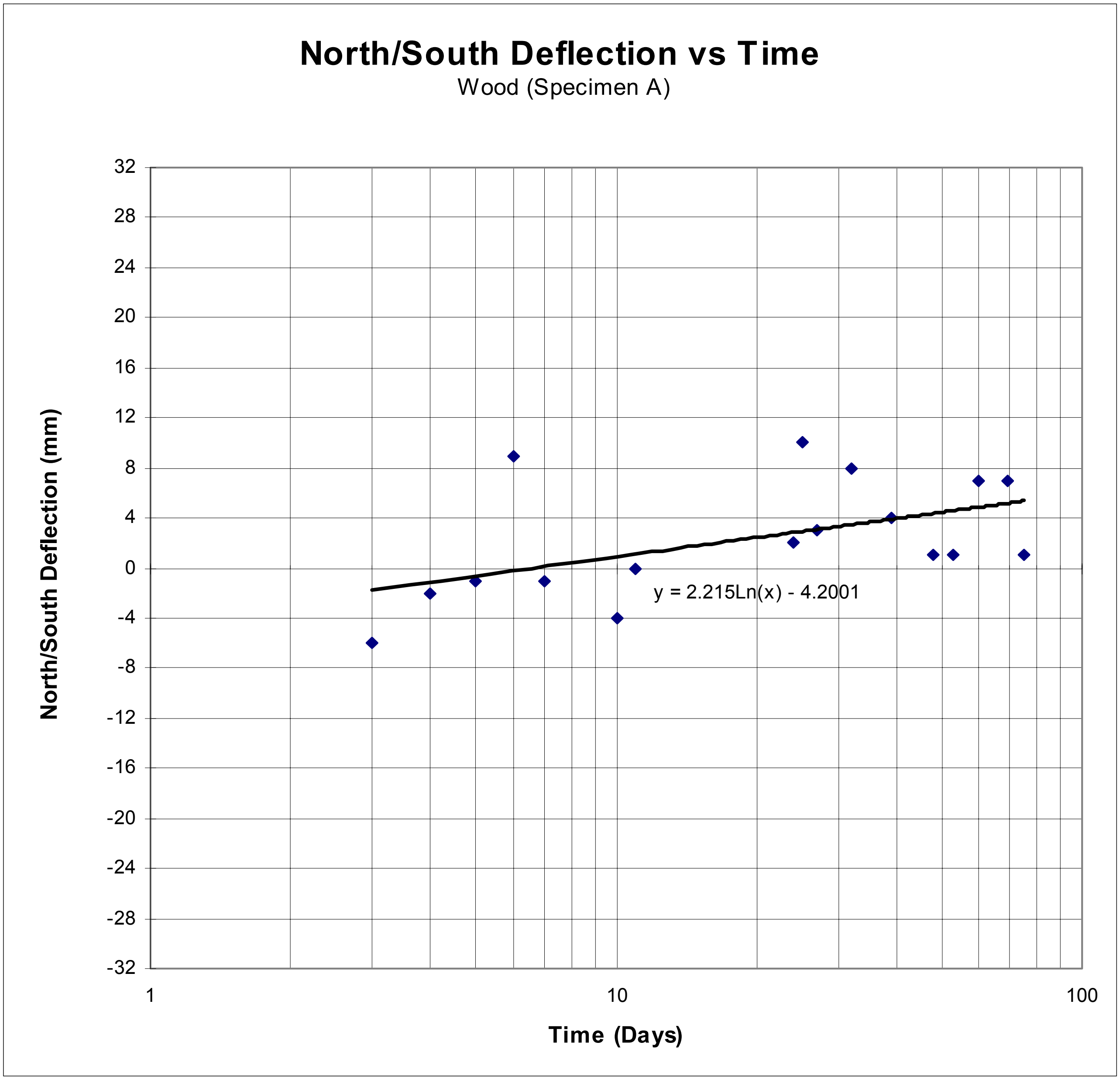

Figure 55. Sample of Warpage of Wood (Specimen A).

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature.

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
2	0	-0.1	0	0.1		0	0.4448	
4	-0.006	-0.4	0.006	0.4	0.0015	0.1524	1.7792	0.169469
6	-0.016	-0.6	0.016	0.6	0.0065	0.4064	2.6688	0.734365
8	-0.023	-1	0.023	1	0.0121	0.5842	4.448	1.367048
10	-0.032	-1.2	0.032	1.2	0.022	0.8128	5.3376	2.485542
12	-0.038	-1.7	0.038	1.7	0.0307	0.9652	7.5616	3.468461
14	-0.044	-2	0.044	2	0.0418	1.1176	8.896	4.722531
16	-0.051	-2.6	0.051	2.6	0.0579	1.2954	11.565	6.541496
18	-0.058	-3.1	0.058	3.1	0.0779	1.4732	13.789	8.795431
20	-0.067	-3.7	0.067	3.7	0.1085	1.7018	16.458	12.25259
22	-0.074	-4.6	0.074	4.6	0.1375	1.8796	20.461	15.53464
24	-0.083	-5.4	0.083	5.4	0.1825	2.1082	24.019	20.6187
26	-0.091	-6.3	0.091	6.3	0.2293	2.3114	28.022	25.90613
28	-0.098	-7.1	0.098	7.1	0.2762	2.4892	31.581	31.20486
30	-0.107	-8.1	0.107	8.1	0.3446	2.7178	36.029	38.93263
32	-0.113	-9	0.113	9	0.3959	2.8702	40.032	44.72847
34	-0.119	-9.9	0.119	9.9	0.4526	3.0226	44.035	51.13439
36	-0.126	-10.9	0.126	10.9	0.5254	3.2004	48.483	59.35927
38	-0.133	-11.9	0.133	11.9	0.6052	3.3782	52.931	68.37501
40	-0.142	-12.9	0.142	12.9	0.7168	3.6068	57.379	80.98349
42	-0.151	-14	0.151	14	0.8379	3.8354	62.272	94.65962
44	-0.157	-15.3	0.157	15.3	0.9258	3.9878	68.054	104.5905
46	-0.166	-16.4	0.166	16.4	1.0684	4.2164	72.947	120.707
48	-0.174	-17.6	0.174	17.6	1.2044	4.4196	78.285	136.0721
50	-0.18	-18.8	0.18	18.8	1.3136	4.572	83.622	148.4095
52	-0.187	-19.8	0.187	19.8	1.4487	4.7498	88.07	163.673
54	-0.194	-21	0.194	21	1.5915	4.9276	93.408	179.8064
56	-0.201	-22.2	0.201	22.2	1.7427	5.1054	98.746	196.8889
58	-0.209	-23.1	0.209	23.1	1.9239	5.3086	102.75	217.3607
60	-0.215	-24.1	0.215	24.1	2.0655	5.461	107.2	233.3585
62	-0.224	-25.4	0.224	25.4	2.2883	5.6896	112.98	258.5247
64	-0.23	-26.1	0.23	26.1	2.4428	5.842	116.09	275.9799
66	-0.241	-27	0.241	27	2.7348	6.1214	120.1	308.9755
68	-0.246	-28	0.246	28	2.8723	6.2484	124.54	324.5102
70	-0.254	-29.3	0.254	29.3	3.1015	6.4516	130.33	350.405
72	-0.262	-30	0.262	30	3.3387	6.6548	133.44	377.2037
74	-0.271	-31	0.271	31	3.6132	6.8834	137.89	408.2164
76	-0.278	-31.7	0.278	31.7	3.8327	7.0612	141	433.0097

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
78	-0.284	-32.8	0.284	32.8	4.0262	7.2136	145.89	454.8712
80	-0.293	-33.6	0.293	33.6	4.325	7.4422	149.45	488.6294
82	-0.298	-34.4	0.298	34.4	4.495	7.5692	153.01	507.8359
84	-0.307	-35.4	0.307	35.4	4.8091	7.7978	157.46	543.3226
86	-0.316	-36.3	0.316	36.3	5.1317	8.0264	161.46	579.7754
88	-0.322	-37.2	0.322	37.2	5.3522	8.1788	165.47	604.6873
90	-0.329	-37.8	0.329	37.8	5.6147	8.3566	168.13	634.3443
92	-0.336	-38.8	0.336	38.8	5.8828	8.5344	172.58	664.634
94	-0.343	-39.8	0.343	39.8	6.1579	8.7122	177.03	695.7146
96	-0.351	-40.5	0.351	40.5	6.4791	8.9154	180.14	732.0035
98	-0.356	-41.5	0.356	41.5	6.6841	9.0424	184.59	755.1643
100	-0.365	-42.2	0.365	42.2	7.0608	9.271	187.71	797.7179
102	-0.374	-43.2	0.374	43.2	7.4451	9.4996	192.15	841.1358
104	-0.38	-44.1	0.38	44.1	7.707	9.652	196.16	870.725
106	-0.388	-45	0.388	45	8.0634	9.8552	200.16	910.9908
108	-0.395	-46.1	0.395	46.1	8.3822	10.033	205.05	947.0143
110	-0.403	-47.1	0.403	47.1	8.755	10.2362	209.5	989.1329
112	-0.412	-48.1	0.412	48.1	9.1834	10.4648	213.95	1037.533
114	-0.418	-49.1	0.418	49.1	9.475	10.6172	218.4	1070.478
116	-0.424	-50.5	0.424	50.5	9.7738	10.7696	224.62	1104.236
118	-0.433	-51.8	0.433	51.8	10.234	10.9982	230.41	1156.246
120	-0.442	-53.5	0.442	53.5	10.708	11.2268	237.97	1209.781
122	-0.448	-55.2	0.448	55.2	11.034	11.3792	245.53	1246.624
124	-0.456	-57.2	0.456	57.2	11.484	11.5824	254.43	1297.419
126	-0.463	-59.1	0.463	59.1	11.891	11.7602	262.88	1343.407
128	-0.471	-61.3	0.471	61.3	12.372	11.9634	272.66	1397.818
130	-0.479	-62.8	0.479	62.8	12.869	12.1666	279.33	1453.901
132	-0.485	-65.2	0.485	65.2	13.253	12.319	290.01	1497.285
134	-0.494	-67.1	0.494	67.1	13.848	12.5476	298.46	1564.547
136	-0.5	-69.1	0.5	69.1	14.257	12.7	307.36	1610.711
138	-0.506	-71.2	0.506	71.2	14.678	12.8524	316.7	1658.264
140	-0.514	-73.1	0.514	73.1	15.255	13.0556	325.15	1723.475
142	-0.523	-75	0.523	75	15.921	13.2842	333.6	1798.77
144	-0.529	-76.8	0.529	76.8	16.377	13.4366	341.61	1850.221
146	-0.537	-78.8	0.537	78.8	16.999	13.6398	350.5	1920.539
148	-0.547	-80.6	0.547	80.6	17.796	13.8938	358.51	2010.583

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
150	-0.553	-82.3	0.553	82.3	18.285	14.0462	366.07	2065.796
152	-0.561	-84	0.561	84	18.95	14.2494	373.63	2140.95
154	-0.568	-85.7	0.568	85.7	19.544	14.4272	381.19	2208.054
156	-0.574	-87.2	0.574	87.2	20.063	14.5796	387.87	2266.656
158	-0.583	-88.6	0.583	88.6	20.854	14.8082	394.09	2356.034
160	-0.589	-90.1	0.589	90.1	21.39	14.9606	400.76	2416.602
162	-0.597	-91.6	0.597	91.6	22.117	15.1638	407.44	2498.716
164	-0.604	-92.8	0.604	92.8	22.762	15.3416	412.77	2571.633
166	-0.614	-94	0.614	94	23.696	15.5956	418.11	2677.155
168	-0.62	-95.3	0.62	95.3	24.264	15.748	423.89	2741.316
170	-0.629	-96.8	0.629	96.8	25.128	15.9766	430.57	2838.981
172	-0.635	-97.8	0.635	97.8	25.712	16.129	435.01	2904.938
174	-0.644	-99.1	0.644	99.1	26.598	16.3576	440.8	3005.043
176	-0.652	-100.2	0.652	100.2	27.395	16.5608	445.69	3095.11
178	-0.658	-101.3	0.658	101.3	28	16.7132	450.58	3163.406
180	-0.664	-102.3	0.664	102.3	28.611	16.8656	455.03	3232.414
182	-0.671	-103.1	0.671	103.1	29.33	17.0434	458.59	3313.635
184	-0.68	-103.9	0.68	103.9	30.261	17.272	462.15	3418.875
186	-0.688	-105.1	0.688	105.1	31.097	17.4752	467.48	3513.325
188	-0.694	-105.8	0.694	105.8	31.73	17.6276	470.6	3584.807
190	-0.702	-106.7	0.702	106.7	32.58	17.8308	474.6	3680.84
192	-0.71	-107.5	0.71	107.5	33.437	18.034	478.16	3777.64
194	-0.717	-108.3	0.717	108.3	34.192	18.2118	481.72	3862.974
196	-0.725	-109.1	0.725	109.1	35.062	18.415	485.28	3961.22
198	-0.731	-109.8	0.731	109.8	35.718	18.5674	488.39	4035.414
200	-0.741	-110.6	0.741	110.6	36.82	18.8214	491.95	4159.917
202	-0.743	-108.6	0.743	108.6	37.039	18.8722	483.05	4184.682
204	-0.75	-110.3	0.75	110.3	37.806	19.05	490.61	4271.241
206	-0.758	-111.6	0.758	111.6	38.693	19.2532	496.4	4371.521
208	-0.764	-112.6	0.764	112.6	39.366	19.4056	500.84	4447.511
210	-0.77	-113.3	0.77	113.3	40.043	19.558	503.96	4524.077
212	-0.781	-113.9	0.781	113.9	41.293	19.8374	506.63	4665.256
214	-0.787	-114.7	0.787	114.7	41.979	19.9898	510.19	4742.737
216	-0.794	-115.3	0.794	115.3	42.784	20.1676	512.85	4833.685
218	-0.804	-115.8	0.804	115.8	43.939	20.4216	515.08	4964.233
220	-0.81	-116.2	0.81	116.2	44.635	20.574	516.86	5042.866

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
222	-0.817	-116.8	0.817	116.8	45.451	20.7518	519.53	5135.001
224	-0.823	-117.3	0.823	117.3	46.153	20.9042	521.75	5214.346
226	-0.831	-117.8	0.831	117.8	47.094	21.1074	523.97	5320.592
228	-0.839	-118.3	0.839	118.3	48.038	21.3106	526.2	5427.289
230	-0.846	-118.8	0.846	118.8	48.868	21.4884	528.42	5521.045
232	-0.854	-119.3	0.854	119.3	49.82	21.6916	530.65	5628.646
234	-0.861	-119.5	0.861	119.5	50.656	21.8694	531.54	5723.074
236	-0.868	-119.8	0.868	119.8	51.494	22.0472	532.87	5817.7
238	-0.876	-120.3	0.876	120.3	52.454	22.2504	535.09	5926.205
240	-0.884	-120.7	0.884	120.7	53.418	22.4536	536.87	6035.117
242	-0.891	-120.8	0.891	120.8	54.263	22.6314	537.32	6130.613
244	-0.901	-121.3	0.901	121.3	55.474	22.8854	539.54	6267.374
246	-0.907	-121.7	0.907	121.7	56.203	23.0378	541.32	6349.736
248	-0.916	-121.8	0.916	121.8	57.298	23.2664	541.77	6473.533
250	-0.921	-122.3	0.921	122.3	57.909	23.3934	543.99	6542.479
252	-0.93	-122.6	0.93	122.6	59.011	23.622	545.32	6666.987
254	-0.934	-122.8	0.934	122.8	59.502	23.7236	546.21	6722.438
256	-0.946	-123.1	0.946	123.1	60.977	24.0284	547.55	6889.127
258	-0.954	-123.3	0.954	123.3	61.963	24.2316	548.44	7000.479
260	-0.962	-123.3	0.962	123.3	62.949	24.4348	548.44	7111.922
262	-0.967	-123.7	0.967	123.7	63.566	24.5618	550.22	7181.687
264	-0.974	-123.7	0.974	123.7	64.432	24.7396	550.22	7279.515
266	-0.983	-124.1	0.983	124.1	65.547	24.9682	552	7405.498
268	-0.991	-124.2	0.991	124.2	66.541	25.1714	552.44	7517.709
270	-0.998	-124.2	0.998	124.2	67.41	25.3492	552.44	7615.934
272	-1.004	-124.3	1.004	124.3	68.156	25.5016	552.89	7700.16
274	-1.01	-124.3	1.01	124.3	70.019	25.654	552.89	7784.419
276	-1.019	-124.2	1.019	124.2		25.8826	552.44	
278	-1.027	-124.2	1.027	124.2		26.0858	552.44	
280	-1.034	-124.2	1.034	124.2		26.2636	552.44	
282	-1.042	-123.9	1.042	123.9		26.4668	551.11	
284	-1.049	-124.1	1.049	124.1		26.6446	552	
286	-1.057	-124.1	1.057	124.1		26.8478	552	
288	-1.065	-123.7	1.065	123.7		27.051	550.22	
290	-1.071	-123.7	1.071	123.7		27.2034	550.22	
292	-1.08	-123.3	1.08	123.3		27.432	548.44	

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
294	-1.086	-123.2	1.086	123.2		27.5844	547.99	
296	-1.095	-123.1	1.095	123.1		27.813	547.55	
298	-1.1	-122.8	1.1	122.8		27.94	546.21	
300	-1.108	-122.6	1.108	122.6		28.1432	545.32	
302	-1.118	-122.2	1.118	122.2		28.3972	543.55	
304	-1.124	-121.7	1.124	121.7		28.5496	541.32	
306	-1.132	-121.2	1.132	121.2		28.7528	539.1	
308	-1.139	-120.8	1.139	120.8		28.9306	537.32	
310	-1.145	-120.2	1.145	120.2		29.083	534.65	
312	-1.153	-119.7	1.153	119.7		29.2862	532.43	
314	-1.162	-118.9	1.162	118.9		29.5148	528.87	
316	-1.168	-118.2	1.168	118.2		29.6672	525.75	
318	-1.176	-117.2	1.176	117.2		29.8704	521.31	
320	-1.185	-116.4	1.185	116.4		30.099	517.75	
322	-1.192	-115.8	1.192	115.8		30.2768	515.08	
324	-1.2	-115.3	1.2	115.3		30.48	512.85	
326	-1.205	-114.4	1.205	114.4		30.607	508.85	
328	-1.214	-113.9	1.214	113.9		30.8356	506.63	
330	-1.221	-113.4	1.221	113.4		31.0134	504.4	
332	-1.229	-112.9	1.229	112.9		31.2166	502.18	
334	-1.238	-112.3	1.238	112.3		31.4452	499.51	
336	-1.244	-111.9	1.244	111.9		31.5976	497.73	
338	-1.25	-111.5	1.25	111.5		31.75	495.95	
340	-1.258	-111.1	1.258	111.1		31.9532	494.17	
342	-1.267	-110.5	1.267	110.5		32.1818	491.5	
344	-1.274	-110.1	1.274	110.1		32.3596	489.72	
346	-1.282	-109.7	1.282	109.7		32.5628	487.95	
348	-1.288	-109.4	1.288	109.4		32.7152	486.61	
350	-1.296	-108.9	1.296	108.9		32.9184	484.39	
352	-1.303	-108.3	1.303	108.3		33.0962	481.72	
354	-1.312	-108	1.312	108		33.3248	480.38	
356	-1.32	-107.7	1.32	107.7		33.528	479.05	
358	-1.327	-107.2	1.327	107.2		33.7058	476.83	
360	-1.335	-106.8	1.335	106.8		33.909	475.05	
362	-1.341	-106.4	1.341	106.4		34.0614	473.27	
364	-1.348	-106.1	1.348	106.1		34.2392	471.93	

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
366	-1.357	-105.7	1.357	105.7		34.4678	470.15	
368	-1.364	-105.2	1.364	105.2		34.6456	467.93	
370	-1.371	-104.9	1.371	104.9		34.8234	466.6	
372	-1.38	-104.6	1.38	104.6		35.052	465.26	
374	-1.385	-104.2	1.385	104.2		35.179	463.48	
376	-1.394	-104.1	1.394	104.1		35.4076	463.04	
378	-1.402	-103.6	1.402	103.6		35.6108	460.81	
380	-1.409	-103.2	1.409	103.2		35.7886	459.03	
382	-1.415	-102.8	1.415	102.8		35.941	457.25	
384	-1.424	-102.5	1.424	102.5		36.1696	455.92	
386	-1.432	-102.1	1.432	102.1		36.3728	454.14	
388	-1.438	-101.7	1.438	101.7		36.5252	452.36	
390	-1.448	-101.3	1.448	101.3		36.7792	450.58	
392	-1.455	-101.2	1.455	101.2		36.957	450.14	
394	-1.461	-100.7	1.461	100.7		37.1094	447.91	
396	-1.468	-100.4	1.468	100.4		37.2872	446.58	
398	-1.476	-100.1	1.476	100.1		37.4904	445.24	
400	-1.484	-99.8	1.484	99.8		37.6936	443.91	
402	-1.487	-97.7	1.487	97.7		37.7698	434.57	
404	-1.493	-98.3	1.493	98.3		37.9222	437.24	
406	-1.502	-98.3	1.502	98.3		38.1508	437.24	
408	-1.508	-98.3	1.508	98.3		38.3032	437.24	
410	-1.516	-97.9	1.516	97.9		38.5064	435.46	
412	-1.525	-97.9	1.525	97.9		38.735	435.46	
414	-1.532	-97.7	1.532	97.7		38.9128	434.57	
416	-1.539	-97.3	1.539	97.3		39.0906	432.79	
418	-1.546	-96.9	1.546	96.9		39.2684	431.01	
420	-1.555	-96.8	1.555	96.8		39.497	430.57	
422	-1.561	-96.3	1.561	96.3		39.6494	428.34	
424	-1.568	-95.9	1.568	95.9		39.8272	426.56	
426	-1.578	-95.7	1.578	95.7		40.0812	425.67	
428	-1.584	-95.2	1.584	95.2		40.2336	423.45	
430	-1.592	-95.1	1.592	95.1		40.4368	423	
432	-1.601	-94.7	1.601	94.7		40.6654	421.23	
434	-1.607	-94.3	1.607	94.3		40.8178	419.45	
436	-1.616	-93.8	1.616	93.8		41.0464	417.22	

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
438	-1.62	-93.4	1.62	93.4		41.148	415.44	
440	-1.629	-93	1.629	93		41.3766	413.66	
442	-1.636	-92.5	1.636	92.5		41.5544	411.44	
444	-1.643	-92.1	1.643	92.1		41.7322	409.66	
446	-1.651	-91.9	1.651	91.9		41.9354	408.77	
448	-1.66	-91.3	1.66	91.3		42.164	406.1	
450	-1.666	-91	1.666	91		42.3164	404.77	
452	-1.674	-90.6	1.674	90.6		42.5196	402.99	
454	-1.682	-90.3	1.682	90.3		42.7228	401.65	
456	-1.69	-89.9	1.69	89.9		42.926	399.88	
458	-1.696	-89.7	1.696	89.7		43.0784	398.99	
460	-1.704	-89.3	1.704	89.3		43.2816	397.21	
462	-1.711	-88.9	1.711	88.9		43.4594	395.43	
464	-1.719	-88.6	1.719	88.6		43.6626	394.09	
466	-1.729	-88.4	1.729	88.4		43.9166	393.2	
468	-1.733	-88	1.733	88		44.0182	391.42	
470	-1.742	-87.9	1.742	87.9		44.2468	390.98	
472	-1.748	-87.2	1.748	87.2		44.3992	387.87	
474	-1.757	-87.2	1.757	87.2		44.6278	387.87	
476	-1.765	-86.7	1.765	86.7		44.831	385.64	
478	-1.771	-86.4	1.771	86.4		44.9834	384.31	
480	-1.777	-86.2	1.777	86.2		45.1358	383.42	
482	-1.786	-85.7	1.786	85.7		45.3644	381.19	
484	-1.794	-85.4	1.794	85.4		45.5676	379.86	
486	-1.801	-85.1	1.801	85.1		45.7454	378.52	
488	-1.808	-85	1.808	85		45.9232	378.08	
490	-1.816	-84.6	1.816	84.6		46.1264	376.3	
492	-1.824	-84.5	1.824	84.5		46.3296	375.86	
494	-1.831	-84.2	1.831	84.2		46.5074	374.52	
496	-1.837	-84.1	1.837	84.1		46.6598	374.08	
498	-1.847	-83.6	1.847	83.6		46.9138	371.85	
500	-1.853	-83.3	1.853	83.3		47.0662	370.52	
502	-1.862	-83.3	1.862	83.3		47.2948	370.52	
504	-1.87	-82.8	1.87	82.8		47.498	368.29	
506	-1.877	-82.7	1.877	82.7		47.6758	367.85	
508	-1.883	-82.3	1.883	82.3		47.8282	366.07	

Table 40. Sample Data from Compression Tests on Offset Blocks at Room Temperature (Continued).

Time (s)	Disp (in)	Load (kips)	Disp (in)	Load (kips)	Fracture Energy (kip-in)	Disp (mm)	Load (kN)	Fracture Energy (kN-mm)
510	-1.891	-81.8	1.891	81.8		48.0314	363.85	

Note: Maximum values are highlighted.

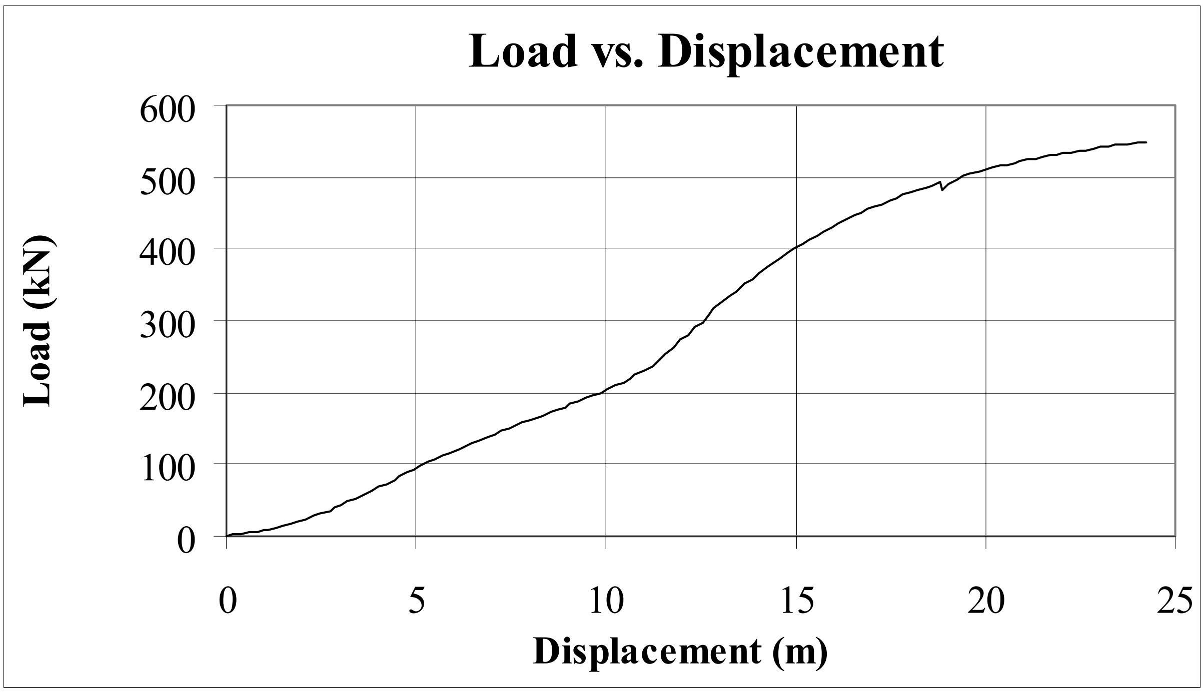

Figure 56. Sample Load-Displacement Curve Obtained from Compression Test on Offset Blocks.