Midwest States' Regional Pooled Fund Research Program
Fiscal Year 1996-1997 (Year 7)
NDOR Research Project Number SPR-3(017)

DYNAMIC TESTING OF WOODEN GUARDRAIL POSTS - WHITE AND RED PINE SPECIES EQUIVALENCY STUDY

Submitted by

John R. Rohde, Ph.D, P.E.
Associate Professor

Jason A. Hascall, B.S.C.E., E.I.T.
Graduate Research Assistant

Karla A. Polivka, M.S.M.E., E.I.T.
Research Associate Engineer

Ronald K. Faller, Ph.D., P.E.
Research Assistant Professor

Dean L. Sicking, Ph.D., P.E.
Professor and MwRSF Director

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-0965

Submitted to

MIDWEST STATES' REGIONAL POOLED FUND PROGRAM
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-154-04

September 21, 2004

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.
TRP-03-154-04		
4. Title and Subtitle		5. Report Date
Dynamic Testing of Wooden Guardrail Posts - White and Red Pine Species Equivalency Study		September 21, 2004
		6.
7. Author(s)		8. Performing Organization Report No.
Rohde, J.R., Hascall, J.A., Polivka, K.A., Faller, R.K., and Sicking, D.L.		TRP-03-154-04
9. Performing Organization Name and Address		10. Project/Task/Work Unit No.
Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, Nebraska 68588-0529		11. Contract © or Grant (G) No. SPR-3(017)
12. Sponsoring Organization Name and Address		13. Type of Report and Period Covered
Midwest States' Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, NE 68502		Final Report 2001-2004
		14. Sponsoring Agency Code
15. Supplementary Notes		
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.		

16. Abstract (Limit: 200 words)

Dynamic impact testing of 152-mm (6-in.) x 203-mm (8-in.) Red, White, and Southern Yellow Pine posts was performed. Dynamic tensile strength of the posts was primarily dependent upon the species of the post, with variation within each species attributable to the inconsistency of wood as a material and defects such as knots in the posts.

The Southern Yellow Pine species tended to have the highest modulus of rupture with an average value of 37.23 MPa (5.40 ksi). White Pine yielded the lowest modulus of rupture, averaging 20.33 MPa (2.95 ksi). The modulus of rupture for Red Pine was 27.44 MPa (3.98 ksi).

Based on these results, it is recommended that the use of Red and White Pine posts as guardrail line posts should require a new cross-sectional depth that would provide equivalent performance to Southern Yellow Pine. The width should remain the same. These changes will provide equivalent performance from Red and White Pine guardrail posts, without changing the soil reaction properties. The suggested depth is 238 mm (9 3/8 in.) for Red Pine species and 264 mm (10 3/8 in.) for White Pine species.

17. Document Analysis/Descriptors		18. Availability Statement	
Highway Safety, Wooden Posts, Red Pine, White Pine, Southern Yellow Pine, Roadside Appurtenances, Bogie Crash Testing		No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	91	

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the State Highway Departments participating in the Midwest States' Regional Pooled Fund Research Program nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest States' Regional Pooled Fund Program funded by the Connecticut Department of Transportation, Illinois Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Montana Department of Transportation, Nebraska Department of Roads, Ohio Department of Transportation, South Dakota Department of Transportation, Texas Department of Transportation, and Wisconsin Department of Transportation for sponsoring this project; (2) Robert D. Slagter from ANRO Timber Products, Inc. for donating the Red Pine and White Pine wood posts; and (3) MwRSF personnel for conducting the crash tests.

Acknowledgment is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

J.C. Holloway, M.S.C.E., E.I.T., Research Associate Engineer
A.T. Russell, Laboratory Mechanic II
Undergraduate and Graduate Assistants

TABLE OF CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

1.1 Background

The performance of W-beam longitudinal barriers is significantly affected by the performance of the posts embedded in soil. Post rotation in soil, fracture of the post, bending of the post, twisting of the post, or a combination of failure modes radically affects how much energy is absorbed by a post in a guardrail system. If the post does not rotate sufficiently in the soil, but fractures or yields soon after impact, there is a significant chance that the barrier will not perform satisfactorily. In cases where wood posts are utilized, the posts must have sufficient structural capacity to displace founding soils and absorb energy. If wood posts that have insufficient bending strength are utilized, the bulk of the impacting vehicle's energy is absorbed by the W-beam element, potentially leading to failure of the rail element and subsequent penetration of the impacting vehicle.

1.2 Objective

The objective of the research project was to determine the properties of the Red and White Pine wood species when used as posts under impact loading conditions. The desired result of this research was to determine an acceptable size of Red and White Pine species in order to allow these species to serve as substitutes for the currently acceptable Southern Yellow Pine (SYP) species in guardrail post applications.

2 LITERATURE REVIEW

2.1 Prior Post Testing Results

In 1995, Rohde et al. (1) completed a study of the effects of grading variation on the performance of wooden posts. The study was requested by the Nebraska Department of Roads (NDOR) in response to the realization that an independent testing laboratory had inaccurately graded lumber installed as guardrail posts from 1989 to 1994.

The results of the study show that there is no significant difference in strength or energy absorption between the nationally accepted standard and the lower grade posts that were installed in Nebraska. These results were based on both the comparison of dynamic testing of Southern Pine Inspection Bureau (SPIB) graded posts and an analysis of BARRIER VII (2) results considering how posts of significantly varying strength affected barrier performance.

3 PHYSICAL TESTING

3.1 Purpose

To assess the dynamic properties of the subject species, physical testing was undertaken to determine failure properties. Past work has shown that dynamic testing at appropriate loading rates is required to accurately assess wood properties.

3.2 Test Facility

Physical testing of 152-mm x 203-mm (6-in x 8-in.) Red, White, and Southern Yellow Pine guardrail posts was performed at the Midwest Roadside Safety Facility (MwRSF) outdoor testing facility located at the Lincoln Air-park on the northwest side of the Lincoln Municipal Airport.

3.3 Scope

Bogie impact tests on the sample posts were performed with the posts installed in a rigid steel sleeve embedded in concrete. The target impact condition for all of the crash tests was a speed of 32 km/h (20 mph) and an angle of 0.0 degrees (deep axis), which has been shown to reflect loading conditions experienced during a longitudinal barrier impact. The posts were impacted 550 mm (21.65 in.) above the ground line perpendicular to the narrow face. The scope of the physical testing is listed in Table 1 and Table 2 below.

Sixty crash tests, WP-1 through WP-30 and RP-1 through RP-30, were conducted, and the test results were analyzed and evaluated. For comparison purposes, fifty-seven previous dynamic bogie post tests were also used. These tests were completed as part of the 1995 NDOR study discussed previously (1).

Table 1. Scope of Physical Testing – White Pine

Test No.	Impact Speed km/h (mph)	Embedment Depth mm (in.)	Moisture Content (%)	X-Axis
WP-1	31.58 (19.62)	965 (38.0)	12.67	Strong
WP-2	31.30 (19.45)	965 (38.0)	10.00	Strong
WP-3	32.88 (20.43)	965 (38.0)	15.67	Strong
WP-4	31.17 (19.37)	965 (38.0)	18.00	Strong
WP-5	32.00 (19.88)	965 (38.0)	9.33	Strong
WP-6	32.14 (19.97)	965 (38.0)	11.67	Strong
WP-7	32.73 (20.34)	965 (38.0)	17.33	Strong
WP-8	31.72 (19.71)	965 (38.0)	12.33	Strong
WP-9	31.58 (19.62)	965 (38.0)	19.00	Strong
WP-10	30.38 (18.88)	965 (38.0)	12.33	Strong
WP-11	31.44 (19.54)	965 (38.0)	14.00	Strong
WP-12	33.96 (21.10)	965 (38.0)	18.00	Strong
WP-13	30.58 (19.0)	965 (38.0)	15.33	Strong
WP-14	39.56 (24.58)	965 (38.0)	10.33	Strong
WP-15	32.43 (20.15)	965 (38.0)	11.00	Strong
WP-16	31.58 (19.62)	965 (38.0)	12.67	Strong
WP-17	32.43 (20.15)	965 (38.0)	14.67	Strong
WP-18	32.00 (19.88)	965 (38.0)	10.67	Strong
WP-19	33.33 (20.71)	965 (38.0)	11.33	Strong
WP-20	34.62 (21.51)	965 (38.0)	16.00	Strong
WP-21	34.95 (21.72)	965 (38.0)	17.00	Strong
WP-22	30.90 (19.20)	965 (38.0)	17.33	Strong
WP-23	34.29 (21.30)	965 (38.0)	17.00	Strong
WP-24	35.29 (21.93)	965 (38.0)	17.67	Strong
WP-25	32.14 (19.97)	965 (38.0)	14.33	Strong
WP-26	30.42 (18.90)	965 (38.0)	16.67	Strong
WP-27	29.27 (18.19)	965 (38.0)	15.00	Strong
WP-28	33.80 (21.0)	965 (38.0)	19.33	Strong
WP-29	34.12 (21.20)	965 (38.0)	15.67	Strong
WP-30	32.43 (20.15)	965 (38.0)	18.33	Strong

Table 2. Scope of Physical Testing – Red Pine

Test No.	Impact Speed km/h (mph)	Embedment Depth mm (in.)	Moisture Content (%)	X-Axis
RP-1	29.29 (18.20)	965 (38.0)	17.33	Strong
RP-2	32.14 (19.97)	965 (38.0)	11.00	Strong
RP-3	31.72 (19.71)	965 (38.0)	11.00	Strong
RP-4	31.58 (19.62)	965 (38.0)	11.33	Strong
RP-5	30.13 (18.72)	965 (38.0)	14.33	Strong
RP-6	30.77 (19.12)	965 (38.0)	17.67	Strong
RP-7	32.29 (20.06)	965 (38.0)	17.33	Strong
RP-8	31.72 (19.71)	965 (38.0)	11.67	Strong
RP-9	32.14 (19.97)	965 (38.0)	11.67	Strong
RP-10	31.72 (19.71)	965 (38.0)	22.00	Strong
RP-11	32.29 (20.06)	965 (38.0)	18.67	Strong
RP-12	32.14 (19.97)	965 (38.0)	16.67	Strong
RP-13	32.14 (19.97)	965 (38.0)	8.00	Strong
RP-14	29.75 (18.49)	965 (38.0)	20.33	Strong
RP-15	30.25 (18.80)	965 (38.0)	22.00	Strong
RP-16	33.96 (21.10)	965 (38.0)	21.33	Strong
RP-17	32.00 (19.88)	965 (38.0)	18.33	Strong
RP-18	31.30 (19.45)	965 (38.0)	19.67	Strong
RP-19	30.90 (19.20)	965 (38.0)	22.67	Strong
RP-20	31.72 (19.71)	965 (38.0)	18.00	Strong
RP-21	31.44 (19.54)	965 (38.0)	16.33	Strong
RP-22	30.64 (19.04)	965 (38.0)	22.67	Strong
RP-23	31.30 (19.45)	965 (38.0)	19.33	Strong
RP-24	30.90 (19.20)	965 (38.0)	18.67	Strong
RP-25	32.58 (20.24)	965 (38.0)	21.00	Strong
RP-26	32.43 (20.15)	965 (38.0)	20.00	Strong
RP-27	31.58 (19.62)	965 (38.0)	16.00	Strong
RP-28	31.58 (19.62)	965 (38.0)	18.33	Strong
RP-29	30.00 (18.64)	965 (38.0)	17.00	Strong
RP-30	37.50 (23.30)	965 (38.0)	16.67	Strong

4 SYSTEM DETAILS

4.1 Wood Post

The posts utilized in this study were cut from White and Red Pine native to Wisconsin. These posts were supplied by ANRO Timber Products, Inc. and selected randomly from a stockpile containing approximately 600 posts of each species. Each specimen was weighed and measured. Moisture contents were collected at three locations along the post (top, center, and bottom), and wane was documented.

Each post was a solid specimen with nominal dimensions of 152 mm x 203 mm x 1,829 mm (6 in. x 8 in. x 72 in.), as shown in Figure 1. Actual cross-sectional measurements were taken at three locations along the posts. Measurements, moisture contents, and weights for the White and Red Pine species are shown in Table 3 and Table 4, respectively.

To complete the test, each post was placed in a 965-mm (38-in.) deep steel sleeve embedded in concrete with 864 mm (34 in.) of the post above the ground. To hold the post in place, neoprene pads of varying dimensions were inserted between the non-impact side of the post and the steel sleeve.

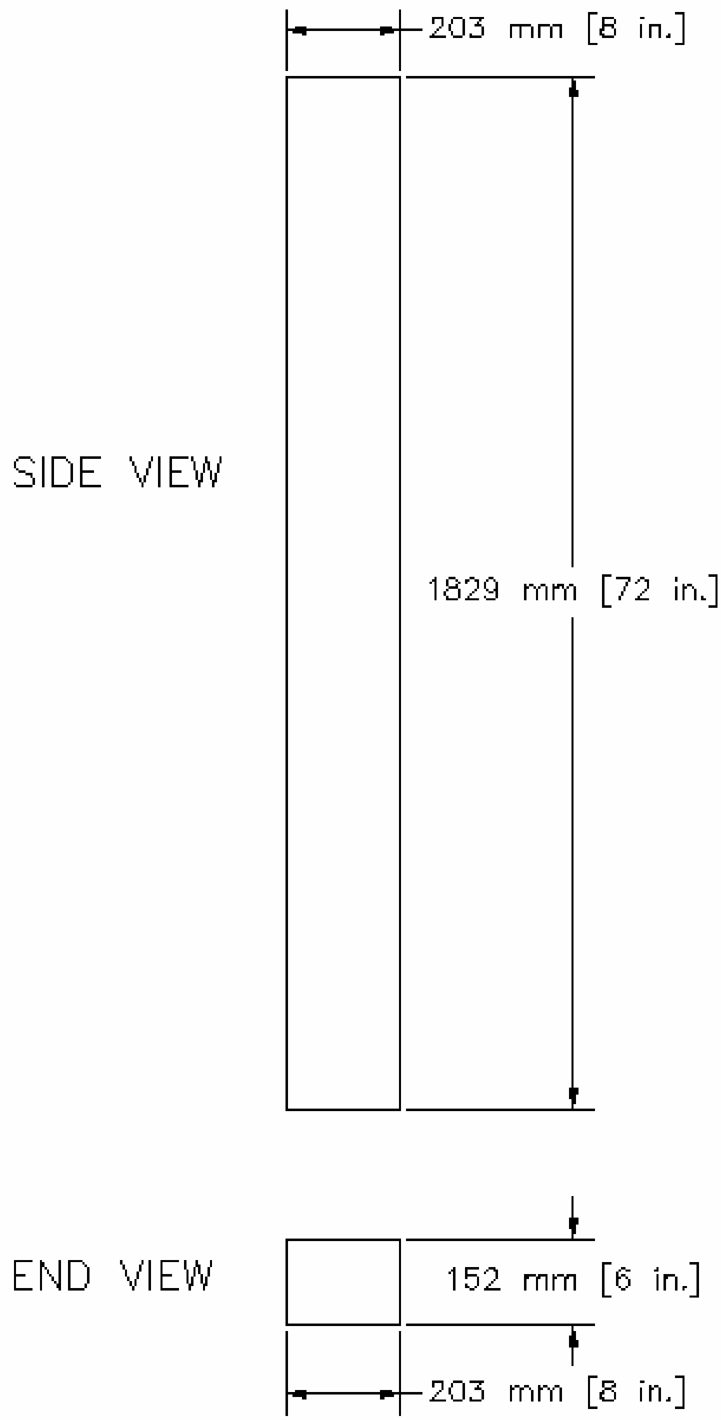


Figure 1. Major Dimensions of the Wooden Guardrail Post

Table 3. Material Properties of White Pine Wooden Posts

	Post #	Weight kg (lbs)	Cross-Section Measurements mm (in.)						Moisture Content (%)			
			Top Width	Top Depth	Center Width	Center Depth	Bottom Width	Bottom Depth	Top	Middle	Bottom	Average
White Pine Species	1	30(66)	152(6.000)	210(8.250)	152(6.000)	210(8.250)	152(6.000)	210(8.250)	12	11	15	13
	2	33(73)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	9	9	12	10
	3	30(66)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	9	20	18	16
	4	34(76)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	18	15	21	18
	5	29(64)	152(6.000)	210(8.250)	152(6.000)	208(8.188)	152(6.000)	210(8.250)	9	9	10	9
	6	24(52)	156(6.125)	210(8.250)	156(6.125)	203(8.000)	152(6.000)	203(8.000)	11	17	7	12
	7	29(63)	152(6.000)	210(8.250)	152(6.000)	206(8.125)	152(6.000)	208(8.188)	15	18	19	17
	8	29(63)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	152(6.000)	208(8.188)	14	11	12	12
	9	32(71)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	16	20	21	19
	10	31(69)	156(6.125)	210(8.250)	156(6.125)	206(8.125)	152(6.000)	206(8.125)	11	13	13	12
	11	36(79)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	11	16	15	14
	12	30(67)	152(6.000)	213(8.375)	152(6.000)	206(8.125)	152(6.000)	203(8.000)	17	18	19	18
	13	38(83)	152(6.000)	210(8.250)	152(6.000)	210(8.250)	156(6.125)	203(8.000)	18	17	11	15
	14	29(65)	152(6.000)	206(8.125)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	10	11	10	10
	15	24(52)	152(6.000)	206(8.125)	156(6.125)	206(8.125)	152(6.000)	206(8.125)	10	15	8	11
	16	28(61)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	13	16	9	13
	17	29(65)	152(6.000)	203(8.000)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	18	13	13	15
	18	33(72)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	152(6.000)	203(8.000)	11	12	9	11
	19	30(67)	152(6.000)	210(8.250)	152(6.000)	208(8.188)	152(6.000)	208(8.188)	10	12	12	11
	20	34(76)	152(6.000)	208(8.188)	152(6.000)	208(8.188)	152(6.000)	208(8.188)	13	19	16	16
	21	33(72)	159(6.250)	210(8.250)	157(6.188)	206(8.125)	159(6.250)	206(8.125)	14	20	17	17
	22	29(65)	133(5.250)	210(8.250)	200(7.875)	206(8.125)	143(5.625)	208(8.188)	14	19	19	17
	23	27(59)	156(6.125)	206(8.125)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	12	20	19	17
	24	31(68)	152(6.000)	210(8.250)	152(6.000)	210(8.250)	152(6.000)	206(8.125)	17	19	17	18
	25	32(71)	159(6.250)	203(8.000)	159(6.250)	206(8.125)	156(6.125)	203(8.000)	12	20	11	14
	26	34(74)	152(6.000)	210(8.250)	152(6.000)	208(8.188)	152(6.000)	206(8.125)	13	18	19	17
	27	30(67)	159(6.250)	210(8.250)	159(6.250)	213(8.375)	156(6.125)	210(8.250)	20	16	9	15
	28	31(69)	156(6.125)	213(8.375)	156(6.125)	213(8.375)	159(6.250)	213(8.375)	21	17	20	19
	29	35(78)	156(6.125)	210(8.250)	156(6.125)	210(8.250)	156(6.125)	210(8.250)	20	11	16	16
	30	29(64)	152(6.000)	206(8.125)	156(6.125)	206(8.125)	156(6.125)	206(8.125)	17	21	17	18

Table 4. Material Properties of Red Pine Wooden Posts

	Post #	Weight kg (lbs)	Cross-Section Measurements mm (in.)						Moisture Content (%)			
			Top Width	Top Depth	Center Width	Center Depth	Bottom Width	Bottom Depth	Top	Middle	Bottom	Average
Red Pine Species	1	34(74)	152(6.000)	197(7.750)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	11	22	19	17
	2	27(59)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	14	11	8	11
	3	28(62)	152(6.000)	197(7.750)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	10	12	11	11
	4	27(59)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	10	12	12	11
	5	33(73)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	9	14	20	14
	6	34(74)	159(6.250)	210(8.250)	159(6.250)	206(8.125)	159(6.250)	206(8.125)	12	20	21	18
	7	34(76)	156(6.125)	206(8.125)	159(6.250)	210(8.250)	162(6.375)	210(8.250)	12	20	20	17
	8	33(72)	156(6.125)	203(8.000)	152(6.000)	203(8.000)	156(6.125)	203(8.000)	11	10	14	12
	9	34(74)	149(5.875)	203(8.000)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	11	12	12	12
	10	29(65)	156(6.125)	210(8.250)	152(6.000)	208(8.188)	156(6.125)	206(8.125)	21	22	23	22
	11	33(73)	156(6.125)	203(8.000)	152(6.000)	210(8.250)	156(6.125)	206(8.125)	21	20	15	19
	12	26(57)	152(6.000)	203(8.000)	152(6.000)	206(8.125)	156(6.125)	206(8.125)	15	16	19	17
	13	29(63)	159(6.250)	203(8.000)	156(6.125)	203(8.000)	152(6.000)	203(8.000)	8	8	8	8
	14	33(72)	152(6.000)	210(8.250)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	24	20	17	20
	15	30(67)	152(6.000)	203(8.000)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	23	22	21	22
	16	34(74)	156(6.125)	203(8.000)	156(6.125)	225(8.875)	156(6.125)	203(8.000)	22	23	19	21
	17	28(61)	146(5.750)	203(8.000)	149(5.875)	203(8.000)	152(6.000)	206(8.125)	17	20	18	18
	18	33(72)	156(6.125)	206(8.125)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	19	21	19	20
	19	33(72)	159(6.250)	203(8.000)	159(6.250)	203(8.000)	159(6.250)	203(8.000)	22	24	22	23
	20	34(75)	156(6.125)	206(8.125)	159(6.250)	206(8.125)	159(6.250)	210(8.250)	14	20	20	18
	21	30(66)	156(6.125)	203(8.000)	156(6.125)	203(8.000)	159(6.250)	206(8.125)	23	11	15	16
	22	29(63)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	152(6.000)	206(8.125)	24	21	23	23
	23	31(69)	154(6.063)	203(8.000)	156(6.125)	206(8.125)	156(6.125)	210(8.250)	22	13	23	19
	24	31(69)	159(6.250)	206(8.125)	162(6.375)	206(8.125)	165(6.500)	210(8.250)	22	15	19	19
	25	28(61)	152(6.000)	206(8.125)	152(6.000)	203(8.000)	152(6.000)	206(8.125)	18	22	23	21
	26	29(65)	152(6.000)	200(7.875)	152(6.000)	203(8.000)	156(6.125)	203(8.000)	19	21	20	20
	27	28(61)	149(5.875)	200(7.875)	156(6.125)	203(8.000)	159(6.250)	203(8.000)	14	18	16	16
	28	28(61)	156(6.125)	189(7.438)	149(5.875)	222(8.750)	152(6.000)	197(7.750)	13	20	22	18
	29	30(67)	156(6.125)	200(7.875)	149(5.875)	200(7.875)	152(6.000)	203(8.000)	14	20	17	17
	30	35(78)	159(6.250)	206(8.125)	152(6.000)	203(8.000)	152(6.000)	203(8.000)	20	16	14	17

4.2 Equipment and Instrumentation

A variety of equipment and instrumentation were used to record and collect data. It is important to gather correct data using affordable instrumentation in order to understand and derive meaningful conclusions of the physical tests. Equipment and instruments utilized in this testing included:

- Bogie
- Accelerometer
- Pressure Tape Switches
- Photography Camera
- Digital Video Camera

4.2.1 Bogie

A rigid-frame bogie was used to impact the posts. An impact head, made of a 203-mm (8-in.) diameter, 12.5-mm (0.5-in.) thick standard steel pipe, was mounted to the bogie with its horizontal centerline 550 mm (21.65 in.) above the ground. Neoprene belting, 19-mm (0.75-in.) thick, was attached to the steel pipe to minimize the local damage to the post from the impact. The bogie is shown in Figure 2.

The bogie weight was 611 kg (1,346 lbs). Calculations and computer simulations prior to testing indicate that this weight, in combination with a velocity of approximately 32 km/h (20 mph or 8.9 m/s) closely replicates the actual impact conditions that a post as part of a guardrail system would be subjected to in a 100 km/h (62.14 mph) and 25-degree impact with a 2,000-kg (4409-lb) test vehicle.

Figure 2. Rigid Frame Bogie

4.2.2 Accelerometer

One triaxial piezoresistive accelerometer system with a range of ±200 G’s was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 was configured with 6 Mb of RAM memory and a 1,500 Hz lowpass filter. Computer software, “DynaMax 1 (DM-1)” and “DADiSP” were used to digitize, analyze, and plot the accelerometer data.

4.2.3 Pressure Tape Switches

Three pressure tape switches, spaced at 1-m (3.3-ft) intervals and placed near the end of the bogie track, were used to determine the speed of the bogie before the impact. As the front left tire of the bogie passed over each tape switch, a strobe light was fired sending an electronic timing signal to the data acquisition system. Test speeds were determined using the time between these signals from the data acquisition system and the known distance between the switches.

4.2.4 Photography Cameras

One high-speed Red Lake E/cam video camera, with an operating speed of 500 frames/sec, and one Canon digital video camera, with an operating speed of 29.97 frames/sec, were used to film a subset of the tests. The cameras were placed approximately 7.62 m (25 ft) away and perpendicular to the bogie's direction of travel. The high-speed footage was only used to confirm accelerometer measurements on a limited number of tests.

4.3 Methodology of Testing

A total of 60 tests, 30 White Pine and 30 Red Pine, were conducted. The posts were impacted along the strong axis of impact with a 965 mm (38.0 in.) embedment depth in a steel sleeve embedded in concrete. Strong axis impact occurs when the bogie head impacts one of the 152 mm (6 in.) faces. A graphical representation of the impact is shown in Figure 3, and the test parameters can be seen in Table 5.

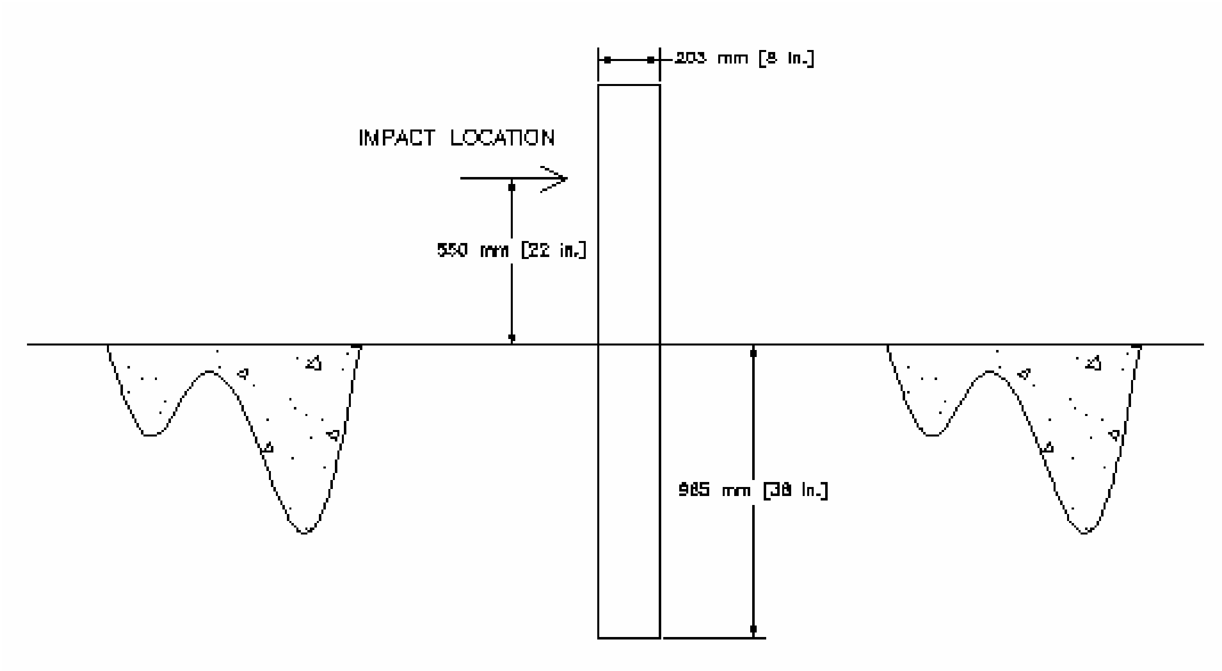


Figure 3. Impact Location

Table 5. Test Parameters

Test Parameters
Test: Strong Axis Impact at 0 degrees
Accelerometer: EDR-4 Data
Bogie Weight: 611 kg (1,346 lbs)
Bumper Height: 550 mm (21.65 in.)
Posts: 152 mm x 203 mm (6 in. x 8 in.) Wooden
Post Length: 1,829 mm (72 in.)
Soil: N/A (Steel sleeve embedded in concrete)

The tests were conducted using a bogie guidance system developed at MwRSF. This system consists of steel pipe supported and anchored by stanchions placed in the concrete every 3.05 m (10 ft). The bogie vehicle is equipped with bearings at the front and back wheels. These bearings surround the pipe keeping the bogie traveling in the direction of the pipe. A pickup truck with a cable system was used to tow the test vehicle, accelerating it to the required impact velocity, at which point the cable was released, allowing the bogie to roll free as it came off the guide track. The bogie positioned on the guide track can be seen in Figure 4.

Figure 4. Bogie Positioned in the Guide Track Configuration

The bearings guided the bogie into the posts to ensure the proper impact direction and position. A remote braking system was installed on the bogie to allow the bogie to be brought safely to a stop after the test. The accelerometer, located at the bogie's center of gravity, records lateral, horizontal and vertical acceleration data.

4.4 End of Test Determination

The end of the test was generally identified at the third time the acceleration data crossed the X-axis from positive to negative. Past this point, the post was considered to be broken. In some cases where the remaining data was clearly irrelevant, the test was ended when the acceleration data crossed the X-axis from positive to negative the first or second time.

4.5 Data Processing

Initially, the bulk of the data was filtered using a SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications. The pertinent acceleration signal was extracted from the bulk of the data. The processed acceleration data was then multiplied by the mass of the bogie to get the impact force using Newton's Second Law. Next, the acceleration trace was integrated to find the change in velocity. Initial velocity of the bogie, calculated using the data from the pressure tape switches, was then used to determine the bogie's velocity trace. The calculated bogie's velocity trace was then integrated to find the displacement. Subsequently, using the previous results, the force-deflection curve was plotted for each test. Finally, integration of the force-deflection curve provides the energy-displacement curve for each test.

5 TEST RESULTS AND DISCUSSION

Accelerometer data was processed for each test in order to obtain acceleration, velocity, and displacement curves, as well as force-deflection curves. Individual test results are provided in Appendix A. A summary of all the tests is provided in Table 6 for the Wisconsin White Pine species, Table 7 for the Wisconsin Red Pine species, and Table 8 for the SYP posts. A summary of the tests for each of the different SYP post grades is provided in Table 9 for Grade 1 Dense posts, Table 10 for Grade 1 posts, Table 11 for Grade 2 Dense posts, and Table 12 for Grade 2 posts.

5.1 Results

The modulus of rupture (MOR) was calculated for each test and is shown in the mentioned tables. The MOR is the stress in the wood fibers at the front and back faces of the post at the point of rupture using an elastic relationship. It is calculated by dividing the bogie impact moment by the section modulus, creating a comparison between posts that is independent of the shape of the post and the speed of the bogie. Furthermore, the MOR values were adjusted to represent MOR values at saturation, 23% moisture content, in order to compensate for the varying strengths due to moisture content variation in the posts. To make this change, the Quadratic Surface Model (Quadratic) was used. This is an empirical adjustment method developed by the United States Department of Agriculture, Forest Service, Forest Products Laboratory (3) that is more accurate, but more computationally intensive than the alternative method given in ASTM D-1990 (4).

After all of the adjustments were made, SYP post testing resulted in the highest MOR value of 28.1 MPa (4.07 ksi). Red Pine, with an average MOR of 22.7 MPa (3.30 ksi), had a higher MOR than White Pine, but was still significantly lower than SYP. White Pine resulted in the lowest MOR value at 16.1 MPa (2.34 ksi).

Table 6. Dynamic White Pine Wood Post Test Results

	Post Test No.	Peak Force				Rupture			Modulus of Rupture	Moisture Content	Adjusted MOR (23% MC Quadratic)	Impact Velocity
		Time	Force	Deflection	Energy	Time	Deflection	Energy				
		ms	kN (kips)	mm (in.)	kJ (kip-in.)	ms	mm (in.)	kJ (kip-in.)	Mpa (k/in.^{2})	(%)	Mpa (k/in.^{2})	m/s (mph)
White Pine Species	1	5.3	35.0 (7.9)	46 (1.8)	0.75 (27.8)	39.3	329 (13.0)	3.14 (27.8)	17.2 (2.50)	13	15 (2.17)	8.8 (19.6)
	2	5.6	39.1 (8.8)	48 (1.9)	0.91 (36.0)	49.8	404 (15.9)	4.06 (36.0)	20.5 (2.98)	10	18 (2.63)	8.7 (19.5)
	3	5.7	41.3 (9.3)	52 (2.0)	1.07 (35.2)	45.7	395 (15.5)	3.98 (35.2)	21.0 (3.05)	16	17 (2.51)	9.1 (20.4)
	4	5.8	37.3 (8.4)	50 (2.0)	0.90 (28.5)	39.1	321 (12.6)	3.22 (28.5)	19.5 (2.83)	18	17 (2.40)	8.7 (19.4)
	5	6	38.4 (8.6)	53 (2.1)	1.03 (23.1)	31.7	271 (10.7)	2.61 (23.1)	19.2 (2.79)	9	18 (2.57)	8.9 (19.9)
	6	5.2	29.4 (6.6)	46 (1.8)	0.65 (14.4)	38.1	333 (13.1)	1.63 (14.4)	15.1 (2.19)	12	14 (1.98)	8.9 (20.0)
	7	5.3	35.8 (8.1)	48 (1.9)	0.82 (19.9)	37.3	328 (12.9)	2.25 (19.9)	18.2 (2.64)	17	16 (2.24)	9.1 (20.3)
	8	5.5	35.1 (7.9)	47 (3.2)	0.79 (21.6)	41.8	317 (13.0)	2.57 (22.7)	17.9 (2.59)	12	16 (2.25)	8.6 (19.3)
	9	9.3	51.7 (11.6)	80 (3.2)	2.42 (21.4)	51.3	414 (16.3)	5.50 (48.7)	27.1 (3.93)	19	23 (3.26)	8.8 (19.6)
	10	9.8	48.5 (10.9)	81 (3.2)	2.44 (33.3)	41.8	330 (13.0)	3.77 (33.3)	24.2 (3.51)	12	20 (2.87)	8.4 (18.9)
	11	10.5	57.2 (12.9)	90 (3.5)	2.80 (40.0)	49.6	403 (15.9)	4.52 (40.0)	30.0 (4.35)	14	23 (3.36)	8.7 (19.5)
	12	5.5	35.7 (8.0)	52 (2.0)	0.89 (31.5)	47.1	424 (16.7)	3.56 (31.5)	18.1 (2.63)	18	16 (2.26)	9.4 (21.1)
	13	5.4	39.4 (8.9)	46 (1.8)	0.84 (26.0)	38.5	312 (12.3)	2.94 (26.0)	19.4 (2.82)	15	16 (2.35)	8.5 (19.0)
	14	5.9	50.0 (11.2)	64 (2.5)	1.50 (67.0)	60.2	607 (23.9)	7.57 (67.0)	26.2 (3.80)	10	22 (3.17)	11.0 (24.6)
	15	5.3	34.2 (7.7)	48 (1.9)	0.77 (17.3)	31.3	274 (10.8)	1.96 (17.3)	17.0 (2.47)	11	15 (2.21)	9.0 (20.2)
	16	5.3	30.9 (7.0)	46 (1.8)	0.66 (16.1)	36.5	311 (12.3)	1.82 (16.1)	16.2 (2.35)	13	14 (2.06)	8.8 (19.6)
	17	5.4	30.6 (6.9)	48 (1.9)	0.70 (17.5)	38	333 (13.1)	1.98 (17.5)	15.5 (2.25)	15	14 (1.97)	9.0 (20.2)
	18	5.3	32.4 (7.3)	47 (1.8)	0.71 (15.8)	37	320 (12.6)	1.79 (15.8)	16.5 (2.39)	11	15 (2.15)	8.9 (19.9)
	19	3.7	13.6 (3.1)	34 (1.3)	0.28 (9.6)	32.7	298 (11.7)	1.08 (9.6)	6.8 (0.99)	11	7 (0.96)	9.3 (20.7)
	20	5.4	45.1 (10.1)	52 (2.0)	1.09 (26.7)	37	344 (13.5)	3.01 (26.7)	22.6 (3.27)	16	18 (2.66)	9.6 (21.5)
	21	5.5	39.8 (8.9)	53 (2.1)	0.99 (22.4)	36.7	344 (13.6)	2.53 (22.4)	19.6 (2.85)	17	16 (2.39)	9.7 (21.7)
	22	10.9	43.3 (9.7)	92 (3.6)	2.33 (38.1)	49.6	396 (15.6)	4.30 (38.1)	16.8 (2.43)	17	15 (2.10)	8.6 (19.2)
	23	5.3	35.3 (7.9)	50 (2.0)	0.85 (21.6)	36.4	336 (13.2)	2.44 (21.6)	18.0 (2.61)	17	15 (2.22)	9.5 (21.3)
	24	5.2	33.3 (7.5)	51 (2.0)	0.81 (15.9)	34.8	333 (13.1)	1.80 (15.9)	16.4 (2.38)	18	14 (2.19)	9.8 (21.9)
	25	5.6	35.9 (8.1)	50 (2.0)	0.86 (30.5)	42.4	360 (14.2)	3.45 (30.5)	17.5 (2.54)	14	15 (2.17)	8.9 (20.0)
	26	5.3	36.5 (8.2)	45 (1.8)	0.76 (24.3)	48.1	389 (15.3)	2.74 (24.3)	18.3 (2.65)	17	16 (2.25)	8.4 (18.9)
	27	5.3	32.3 (7.3)	43 (1.7)	0.63 (15.8)	36	285 (11.2)	1.78 (15.8)	14.8 (2.15)	15	13 (1.91)	8.1 (18.2)
	28	10.5	40.4 (9.1)	97 (3.8)	2.47 (35.4)	43.7	389 (15.3)	4.00 (35.4)	18.9 (2.75)	19	16 (2.38)	9.4 (21.0)
	29	5.2	37.1 (8.3)	49 (1.9)	0.86 (18.2)	35.2	325 (12.8)	2.06 (18.2)	17.9 (2.60)	16	15 (2.27)	9.5 (21.2)
	30	5.4	34.2 (7.7)	48 (1.9)	0.78 (23.7)	35.2	304 (12.0)	2.68 (23.7)	17.1 (2.47)	18	15 (2.15)	9.0 (20.2)
	Avg.	**6.18**	**37.6 (8.5)**	**55 (2.2)**	**1.11 (25.8)**	**40.7**	**351 (13.8)**	**3.02 (26.8)**	**18.8 (2.73)**	**15**	**16.1 (2.34)**	**9.0 (20.2)**
	St. Dev.	**1.8814**	**8.0 (1.8)**	**16 (0.6)**	**0.66 (11.1)**	**6.8**	**64 (2.5)**	**1.33 (11.8)**	**4.2 (0.60)**	**3**	**3.1 (0.45)**	**0.6 (1.2)**

Table 7. Dynamic Red Pine Wood Post Test Results

	Post Test No.	Peak Force				Rupture			Modulus of Rupture	Moisture Content	Adjusted MOR (23% MC Quadratic)	Impact Velocity
		Time ms	Force kN (kips)	Deflection mm (in.)	Energy kJ (kip-in.)	Time ms	Deflection mm (in.)	Energy kJ (kip-in.)	Mpa (k/in.^{2})	(%)	Mpa (k/in.^{2})	m/s (mph)
Red Pine Species	1	10.2	84.5 (19.0)	81 (3.2)	3.35 (29.6)	82.8	560 (22.1)	7.66 (67.8)	44.3 (6.43)	17	34.1 (4.95)	8.1 (18.2)
	2	8.9	51.6 (11.6)	78 (3.1)	2.37 (21.0)	42.6	354 (13.9)	4.41 (39.0)	27.0 (3.92)	11	21.9 (3.18)	8.9 (20.0)
	3	9.5	66.0 (14.8)	82 (3.2)	2.77 (24.6)	43.9	357 (14.1)	5.04 (44.6)	34.6 (5.02)	11	26.6 (3.86)	8.8 (19.7)
	4	5.2	36.1 (8.1)	45 (1.8)	0.76 (6.7)	30.2	254 (10.0)	2.95 (26.1)	19.0 (2.75)	11	16.6 (2.41)	8.8 (19.6)
	5	10	86.1 (19.3)	81 (3.2)	3.45 (30.5)	80.1	552 (21.7)	8.58 (76.0)	45.1 (6.54)	14	33.0 (4.78)	8.4 (18.7)
	6	5.7	49.7 (11.2)	48 (1.9)	1.16 (10.2)	39	314 (12.4)	3.76 (33.3)	24.2 (3.52)	18	19.9 (2.89)	8.5 (19.1)
	7	10.9	91.0 (20.4)	95 (3.7)	4.39 (38.8)	43.8	343 (13.5)	8.27 (73.2)	43.1 (6.24)	17	33.2 (4.81)	9.0 (20.1)
	8	10.5	95.3 (21.4)	90 (3.5)	4.18 (37.0)	46	349 (13.8)	8.20 (72.6)	50.0 (7.25)	12	35.6 (5.16)	8.8 (19.7)
	9	13.3	83.0 (18.7)	115 (4.5)	3.98 (35.2)	50.2	390 (15.4)	8.15 (72.1)	43.5 (6.31)	12	31.7 (4.60)	8.9 (20.0)
	10	5.6	34.4 (7.7)	49 (1.9)	0.82 (7.3)	42.5	354 (14.0)	3.68 (32.5)	17.2 (2.50)	22	16.4 (2.38)	8.8 (19.7)
	11	5.7	43.8 (9.9)	50 (2.0)	1.11 (9.8)	43	357 (14.1)	4.35 (38.5)	21.6 (3.14)	19	18.3 (2.67)	8.9 (19.9)
	12	6.2	38.5 (8.7)	54 (2.1)	1.09 (9.7)	45.7	375 (14.8)	4.71 (41.7)	19.6 (2.84)	17	16.4 (2.38)	8.8 (19.7)
	13	5.3	35.0 (7.9)	47 (1.9)	0.77 (6.8)	43.3	370 (14.6)	3.00 (26.6)	18.0 (2.60)	8	17.4 (2.52)	8.9 (19.9)
	14	11.1	54.3 (12.2)	88 (3.5)	2.73 (24.2)	41.7	311 (12.3)	4.65 (41.2)	27.6 (4.01)	20	23.6 (3.43)	8.1 (18.2)
	15	5.8	35.8 (8.0)	48 (1.9)	0.82 (7.2)	63.5	491 (19.3)	4.53 (40.1)	18.2 (2.64)	22	17.3 (2.51)	8.4 (18.8)
	16	5.5	48.0 (10.8)	52 (2.0)	1.19 (10.5)	41.4	370 (14.5)	3.78 (33.4)	20.0 (2.91)	21	18.1 (2.64)	9.4 (21.1)
	17	8.3	53.5 (12.0)	72 (2.8)	2.19 (19.4)	60.6	489 (19.2)	5.11 (45.2)	28.7 (4.16)	18	23.1 (3.35)	8.8 (19.8)
	18	10.7	72.9 (16.4)	91 (3.6)	3.22 (28.5)	45.8	363 (14.3)	5.68 (50.2)	38.2 (5.55)	20	32.5 (4.72)	8.7 (19.5)
	19	5.4	31.2 (7.0)	46 (1.8)	0.69 (6.1)	45.3	370 (14.6)	3.14 (27.8)	15.7 (2.28)	23	15.7 (2.28)	8.4 (18.9)
	20	10.3	65.0 (14.6)	88 (3.5)	3.28 (29.1)	45.3	363 (14.3)	5.75 (50.8)	31.7 (4.60)	18	25.4 (3.68)	8.8 (19.7)
	21	10.3	47.4 (10.7)	88 (3.5)	2.36 (20.9)	45	369 (14.5)	4.05 (35.8)	24.3 (3.53)	16	19.5 (2.83)	8.7 (19.5)
	22	6	38.9 (8.8)	51 (2.0)	0.98 (8.7)	50.4	403 (15.9)	3.83 (33.9)	19.8 (2.87)	23	19.8 (2.87)	8.5 (19.0)
	23	9.5	54.0 (12.1)	81 (3.2)	2.47 (21.8)	52.9	414 (16.3)	6.07 (53.7)	26.9 (3.90)	19	22.3 (3.24)	8.7 (19.5)
	24	11.6	41.0 (9.2)	98 (3.8)	2.37 (21.0)	45.6	369 (14.5)	3.48 (30.8)	19.6 (2.85)	19	16.9 (2.45)	8.6 (19.2)
	25	8	43.5 (9.8)	71 (2.8)	1.91 (16.9)	37	319 (12.6)	3.82 (33.8)	22.8 (3.31)	21	20.5 (2.98)	9.1 (20.2)
	26	10.7	64.0 (14.4)	94 (3.7)	3.22 (28.5)	45	373 (14.7)	5.54 (49.0)	33.5 (4.86)	20	28.5 (4.13)	9.0 (20.2)
	27	9.7	38.4 (8.6)	84 (3.3)	2.12 (18.8)	44.6	369 (14.5)	4.02 (35.6)	19.7 (2.86)	16	16.4 (2.38)	8.8 (19.6)
	28	10.5	40.4 (9.1)	90 (3.6)	2.30 (20.4)	43.7	362 (14.2)	3.73 (33.0)	18.1 (2.62)	18	15.5 (2.25)	8.8 (19.6)
	29	10.4	54.0 (12.1)	85 (3.3)	2.64 (23.4)	42.5	327 (12.9)	4.52 (40.0)	29.8 (4.33)	17	23.5 (3.42)	8.3 (18.6)
	30	5.9	53.8 (12.1)	61 (2.4)	1.66 (14.7)	12.9	130 (5.1)	3.90 (34.5)	28.2 (4.09)	17	22.4 (3.25)	10.4 (23.3)
	Avg.	**8.4**	**53.9 (12.1)**	**72 (2.9)**	**2.16 (19.1)**	**45.1**	**360 (14.2)**	**4.75 (42.0)**	**27.7 (4.01)**	**17**	**22.7 (3.30)**	**8.8 (19.7)**
	St. Dev.	**2.5**	**18.6 (4.2)**	**21 (0.8)**	**1.13 (10.0)**	**13.1**	**83 (3.3)**	**1.83 (16.2)**	**9.6 (1.40)**	**4**	**6.3 (0.92)**	**0.4 (0.9)**

Table 8. Summary of 1995 NDOR Dynamic Southern Yellow Pine Wood Post Test Results

Grade	Number of Posts	Peak Force: Force kN (kips)	Peak Force: Time ms	Peak Force: Deflection mm (in)	Peak Force: Energy kN-mm (kip-in)	Rupture: Time ms	Rupture: Deflection mm (in)	Rupture: Energy kN-mm (kip-in)	Modulus of Rupture Mpa (k/in.^{2})	Moisture Content %	Adjusted MOR (23% MC Quadratic) Mpa (k/in.^{2})
Grade 1D	16	49.59 (11.14)	8.16	78 (3.07)	2253 (19.94)	15.35	145 (5.70)	4184 (37.02)	28.68 (4.16)	31	28.51 (4.14)
Grade 1	9	46.73 (10.50)	8.26	81 (3.21)	2141 (18.95)	15.54	151 (5.95)	4100 (36.27)	27.03 (3.92)	32	26.65 (3.87)
Grade 2D	16	51.77 (11.63)	8.55	83 (3.26)	2406 (21.28)	17.54	166 (6.55)	4725 (41.80)	30.81 (4.47)	35	30.81 (4.47)
Grade 2	16	44.58 (10.02)	9.10	88 (3.46)	2134 (18.88)	16.68	159 (6.25)	4007 (35.45)	26.25 (3.81)	34	26.18 (3.80)
	Average	48.17 (10.82)	8.52	83 (3.25)	2234 (19.76)	16.28	155 (6.11)	4254 (37.64)	28.19 (4.09)	32.98	28.04 (4.07)

Table 9. Grade 1 Dense 1995 NDOR Testing Results

Year Installed	Post Number	Grade: SPIB	Grade: Special	Peak Force: Force kN (kips)	Peak Force: Time (ms)	Peak Force: Deflection mm (in.)	Peak Force: Energy kJ (kip-in.)	Rupture: Time (ms)	Rupture: Deflection mm (in.)	Rupture: Energy kJ (kip-in.)	Impact Velocity m/s (mph)	Modulus of Rupture MPa (k/in.^{2})	Moisture Content (%)	Adjusted MOR (23% Quadratic) MPa (k/in.^{2})
1989	8	1D	1D	65.0 (14.6)	7.8	75 (3.0)	2.76 (24.4)	15.3	145 (5.7)	5.52 (48.8)	9.7 (21.8)	38.9 (5.64)	N/A	38.9 (5.64)
1992	168	1D	1D	68.5 (15.4)	8.4	79 (3.1)	3.16 (28.0)	15.9	147 (5.8)	5.79 (51.2)	9.5 (21.3)	40.5 (5.87)	37	40.5 (5.87)
1992	176	1D	1D	35.1 (7.9)	7.8	75 (2.9)	1.53 (13.5)	14.7	139 (5.5)	2.85 (25.2)	9.6 (21.5)	20.4 (2.97)	N/A	20.4 (2.97)
1994	209	1D	1D	57.8 (13.0)	8.4	77 (3.0)	2.48 (21.9)	15.6	140 (5.5)	4.71 (41.6)	9.2 (20.6)	34.9 (5.06)	39	34.9 (5.06)
1989	314	1D	1D	73.6 (16.5)	8.4	85 (3.3)	4.26 (37.7)	15.6	153 (6.0)	6.47 (57.3)	10.1 (22.7)	41.2 (5.97)	22	39.4 (5.71)
1992	504	1D	1D	39.2 (8.8)	8.1	79 (3.1)	1.79 (15.8)	15.3	146 (5.8)	3.37 (29.8)	9.7 (21.8)	21.6 (3.14)	24	21.6 (3.14)
1994	559	1D	1D	49.4 (11.1)	7.8	74 (2.9)	2.11 (18.7)	15.0	141 (5.5)	4.06 (35.9)	9.6 (21.5)	31.1 (4.52)	N/A	31.1 (4.52)
1989	613	1D	1D	48.5 (10.9)	8.8	81 (3.2)	2.16 (19.2)	15.9	145 (5.7)	4.08 (36.1)	9.3 (20.8)	28.4 (4.12)	48	28.4 (4.12)
1989	620	1D	1D	40.2 (9.0)	7.8	76 (3.0)	1.77 (15.7)	14.7	142 (5.6)	3.38 (29.9)	9.8 (22.0)	23.5 (3.41)	N/A	23.5 (3.41)
1990	626	1D	1D	51.2 (11.5)	8.4	84 (3.3)	2.39 (21.2)	15.6	153 (6.0)	4.49 (39.7)	10.0 (22.4)	29.4 (4.27)	32	29.4 (4.27)
1992	704	1D	1D	48.5 (10.9)	7.8	74 (2.9)	2.00 (17.7)	15.3	144 (5.7)	3.99 (35.3)	9.5 (21.3)	27.0 (3.92)	N/A	27.0 (3.92)
1994	1128	1D	1D	41.3 (9.3)	7.8	71 (2.8)	1.70 (15.1)	14.7	131 (5.2)	3.21 (28.4)	9.1 (20.4)	22.4 (3.25)	N/A	22.4 (3.25)
1992	1151	1D	1D	43.3 (9.7)	7.8	78 (3.1)	1.96 (17.3)	15.9	158 (6.2)	3.91 (34.6)	10.1 (22.6)	26.7 (3.87)	23	26.7 (3.87)
1994	1222	1D	1D	59.2 (13.3)	8.1	79 (3.1)	2.62 (23.2)	15.0	144 (5.7)	4.92 (43.5)	9.8 (22.0)	30.5 (4.43)	N/A	30.5 (4.43)
1989	1407	1D	1D	38.8 (8.7)	7.8	75 (3.0)	1.71 (15.2)	14.4	143 (5.6)	3.28 (29.0)	10.1 (22.6)	22.4 (3.25)	22	21.5 (3.12)
1989	1419	3	1D	33.8 (7.6)	9.4	86 (3.4)	1.63 (14.4)	16.6	150 (5.9)	2.93 (25.9)	9.2 (20.6)	19.9 (2.88)	26	19.9 (2.88)
			Average	49.6 (11.1)	8.2	78 (3.1)	2.25 (19.9)	15.4	145 (5.7)	4.18 (37.0)	9.7 (21.6)	28.7 (4.16)	30	28.5 (4.14)

Table 10. Grade 1 1995 NDOR Testing Results

Year Installed	Post Number	Grade SPIB	Grade Special	Peak Force: Force kN (kips)	Peak Force: Time (ms)	Peak Force: Deflection mm (in.)	Peak Force: Energy kJ (kip-in.)	Rupture: Time (ms)	Rupture: Deflection mm (in.)	Rupture: Energy kJ (kip-in.)	Impact Velocity m/s (mph)	Modulus of Rupture MPa (k/in.^{2})	Moisture Content (%)	Adjusted MOR (23% Quadratic) MPa (k/in.^{2})
1989	14		1	46.3 (10.4)	8.4	84 (3.3)	2.20 (19.4)	16.6	163 (6.4)	4.29 (37.9)	10.1 (22.5)	27.1 (3.94)	38	27.1 (3.94)
1989	657		1	48.0 (10.8)	8.1	81 (3.2)	2.25 (19.9)	15.0	148 (5.8)	4.20 (37.2)	10.1 (22.5)	27.8 (4.03)	31	27.8 (4.03)
1989	1027		1	41.9 (9.4)	8.1	78 (3.1)	1.86 (16.5)	14.7	139 (5.5)	3.43 (30.3)	9.7 (21.6)	22.3 (3.23)	41	22.3 (3.23)
1990	303		1	35.6 (8.0)	8.4	81 (3.2)	1.69 (15.0)	16.3	154 (6.1)	3.16 (27.9)	9.7 (21.6)	20.5 (2.97)	20	17.8 (2.58)
1992	179		1	51.2 (11.5)	8.1	85 (3.3)	2.38 (21.1)	15.3	157 (6.2)	4.68 (41.4)	10.5 (23.5)	30.1 (4.36)	32	30.1 (4.36)
1994	773		1	38.3 (8.6)	8.4	80 (3.1)	1.68 (14.9)	15.9	149 (5.9)	3.26 (28.9)	9.5 (21.3)	22.1 (3.21)	25	22.1 (3.21)
1994	1112		1	65.8 (14.8)	8.1	81 (3.2)	2.92 (25.8)	15.0	147 (5.8)	5.68 (50.3)	10.1 (22.6)	39.3 (5.70)	39	39.3 (5.70)
			Average	46.7 (10.5)	8.3	81 (3.2)	2.14 (18.9)	15.5	151 (5.9)	4.10 (36.3)	9.9 (22.2)	27.0 (3.92)	32	26.6 (3.87)

Table 11. Grade 2 Dense 1995 NDOR Testing Results

Year Installed	Post Number	Grade SPIB	Grade Special	Peak Force: Force kN (kips)	Peak Force: Time (ms)	Peak Force: Deflection mm (in.)	Peak Force: Energy kJ (kip-in.)	Rupture: Time (ms)	Rupture: Deflection mm (in.)	Rupture: Energy kJ (kip-in.)	Impact Velocity m/s (mph)	Modulus of Rupture MPa (k/in.^{2})	Moisture Content (%)	Adjusted MOR (23% Quadratic) MPa (k/in.^{2})
1989	5	2D	2D	81.6 (18.3)	8.4	80 (3.1)	3.69 (32.6)	15.6	175 (5.7)	6.86 (60.7)	9.6 (21.4)	48.6 (7.04)	39	48.6 (7.04)
1989	51	3	2D	54.9 (12.3)	9.1	88 (3.5)	2.56 (22.7)	16.6	139 (6.2)	5.02 (44.4)	9.8 (21.9)	27.2 (3.94)	27	27.2 (3.94)
1992	111	2D	2D	81.5 (18.3)	8.8	79 (3.1)	3.54 (31.4)	15.9	236 (5.5)	6.58 (58.2)	9.1 (20.4)	45.9 (6.65)	36	45.9 (6.65)
1992	156	2D	2D	57.3 (12.9)	9.1	88 (3.5)	2.84 (25.1)	16.9	145 (6.3)	5.29 (46.8)	9.8 (22.0)	33.8 (4.90)	30	33.8 (4.90)
1994	207	2D	2D	90.4 (20.3)	9.1	92 (3.6)	4.43 (39.2)	17.8	160 (6.9)	8.85 (78.3)	10.3 (23.0)	57.1 (8.29)	30	57.1 (8.29)
1990	305	2D	2D	31.8 (7.1)	8.1	78 (3.1)	1.41 (12.5)	36.9	178 (13.5)	5.07 (44.8)	9.6 (21.5)	18.9 (2.75)	25	18.9 (2.75)
1990	321	2D	2D	26.1 (5.9)	7.8	74 (2.9)	1.10 (9.7)	15.0	129 (5.6)	2.16 (19.1)	9.6 (21.4)	15.2 (2.21)	25	15.2 (2.21)
1992	501	2D	2D	64.0 (14.4)	8.4	84 (3.3)	3.10 (27.5)	15.9	162 (6.1)	5.80 (51.3)	10.0 (22.4)	36.2 (5.25)	27	36.2 (5.25)
1992	510	2D	2D	47.9 (10.8)	8.1	73 (2.9)	1.95 (17.2)	15.3	145 (5.3)	3.78 (33.5)	9.1 (20.3)	26.9 (3.91)	29	26.9 (3.91)
1992	518	2D	2D	45.3 (10.2)	9.4	91 (3.6)	2.25 (19.9)	16.6	165 (6.3)	4.15 (36.7)	9.8 (22.0)	25.0 (3.63)	31	25.0 (3.63)
1994	576	2D	2D	84.8 (19.1)	8.4	83 (3.2)	3.90 (34.5)	15.9	162 (6.0)	7.40 (65.5)	9.9 (22.2)	50.1 (7.26)	50	50.1 (7.26)
1989	603	3	2D	31.7 (7.1)	7.5	72 (2.8)	1.37 (12.2)	14.1	145 (5.3)	2.53 (22.4)	9.7 (21.6)	18.8 (2.73)	72	18.8 (2.73)
1989	619	2D	2D	55.0 (12.4)	8.4	82 (3.2)	2.56 (22.7)	16.3	148 (6.1)	4.89 (43.3)	9.8 (21.9)	31.4 (4.55)	47	31.4 (4.55)
1989	670	E	2D	29.1 (6.5)	8.1	79 (3.1)	1.33 (11.7)	16.3	160 (6.2)	2.59 (23.0)	9.8 (21.9)			
1992	1160	2D	2D	13.6 (3.1)	9.1	91 (3.6)	0.69 (6.1)	19.1	147 (7.5)	1.42 (12.6)	10.0 (22.4)	7.7 (1.12)	29	7.7 (1.12)
1989	1423	2D	2D	33.3 (7.5)	9.1	91 (3.6)	1.75 (15.5)	16.6	147 (6.5)	3.20 (28.3)	10.1 (22.6)	19.4 (2.81)	23	19.4 (2.81)
			Average	51.8 (11.6)	8.6	83 (3.3)	2.41 (21.3)	17.5	159 (6.5)	4.72 (41.8)	9.7 (21.8)	30.8 (4.47)	35	30.8 (4.47)

Table 12. Grade 2 1995 NDOR Testing Results.

Year Installed	Post Number	Grade		Peak Force				Rupture			Impact Velocity	Modulus of Rupture	Moisture Content	Adjusted MOR (23%
		SPIB	Special	Force kN (kips)	Time (ms)	Deflection mm (in.)	Energy kJ (kip-in.)	Time (ms)	Deflection mm (in.)	Energy kJ (kip-in.)	m/s (mph)	MPa (k/in.^{2})	(%)	MPa (k/in.^{2})
1989	74	3	2	47.6 (10.7)	9.4	92 (3.6)	2.35 (20.8)	18.1	175 (6.9)	4.73 (41.9)	9.9 (22.2)	28.6 (4.15)	24	28.6 (4.15)
1992	109	2	2	41.9 (9.4)	8.1	78 (3.1)	1.86 (16.4)	14.7	139 (5.5)	3.42 (30.2)	9.7 (21.8)	23.5 (3.40)	26	23.5 (3.40)
1990	306	2	2	33.1 (7.4)	13.8	145 (5.7)	2.08 (18.4)	22.5	236 (9.3)	3.91 (34.6)	10.6 (23.8)	19.1 (2.77)	23	19.1 (2.77)
NA	407	3	3	28.0 (6.3)	8.1	77 (3.0)	1.26 (11.1)	15.3	145 (5.7)	2.32 (20.5)	9.6 (21.4)	17.0 (2.46)	29	17.0 (2.46)
NA	425	2	2	40.0 (9.0)	9.4	90 (3.5)	1.99 (17.6)	16.9	160 (6.3)	3.71 (32.8)	9.7 (21.6)	24.0 (3.49)	33	24.0 (3.49)
NA	426	2	2	31.6 (7.1)	10.6	103 (4.1)	1.73 (15.3)	18.4	178 (7.0)	3.16 (28.0)	9.8 (21.9)	18.8 (2.72)	35	18.8 (2.72)
1994	572	2	2	45.8 (10.3)	8.1	71 (2.8)	1.80 (16.0)	15.0	129 (5.1)	3.45 (30.5)	8.8 (19.7)	27.5 (3.99)	45	27.5 (3.99)
1989	609	2	2	42.3 (9.5)	8.8	85 (3.3)	2.00 (17.7)	16.9	162 (6.4)	3.87 (34.3)	9.8 (21.9)	25.1 (3.65)	55	25.1 (3.65)
1989	625	2	2	67.7 (15.2)	8.4	79 (3.1)	3.07 (27.2)	15.9	145 (5.7)	5.71 (50.5)	9.4 (21.1)	39.4 (5.72)	64	39.4 (5.72)
1989	630	2	2	62.5 (14.0)	9.7	92 (3.6)	3.10 (27.4)	17.8	165 (6.5)	5.85 (51.7)	9.6 (21.4)	35.8 (5.19)	60	35.8 (5.19)
1989	662	3	2	34.6 (7.8)	8.8	90 (3.5)	1.77 (15.6)	15.9	162 (6.4)	3.27 (28.9)	10.3 (23.1)	20.4 (2.95)	24	20.4 (2.95)
1989	669	3	2	45.7 (10.3)	7.8	75 (2.9)	1.96 (17.3)	15.3	145 (5.7)	3.88 (34.3)	9.7 (21.6)	27.4 (3.97)	26	27.4 (3.97)
1989	676	2	2	58.5 (13.1)	9.1	84 (3.3)	2.83 (25.0)	16.3	148 (5.8)	5.04 (44.6)	9.4 (21.0)	34.7 (5.04)	34	34.7 (5.04)
1994	763	3	2	61.2 (13.8)	9.7	90 (3.6)	3.04 (26.9)	17.5	160 (6.3)	5.57 (49.2)	9.4 (21.1)	35.7 (5.18)	27	35.7 (5.18)
1994	766	3	2	40.6 (9.1)	8.1	79 (3.1)	1.82 (16.1)	15.3	147 (5.8)	3.44 (30.5)	9.8 (21.9)	24.1 (3.50)	26	24.1 (3.50)
1994	768	2	2	32.1 (7.2)	7.8	77 (3.0)	1.50 (13.3)	15.0	147 (5.8)	2.78 (24.6)	10.0 (22.3)	18.9 (2.74)	22	17.8 (2.58)
			Average	44.6 (10.0)	9.1	88 (3.5)	2.13 (18.9)	16.7	159 (6.3)	4.01 (35.5)	9.7 (21.7)	26.3 (3.81)	34	26.2 (3.80)

5.2 Force Discussion

The ability for a guardrail post to rotate in soil is based on having a sufficient modulus of rupture to overcome soil resistance. Therefore, the key factor in determining the acceptability of an alternative wood species is based on a comparison between the peak capacities.

5.2.1 Tests WP-1 through WP-30

The average peak force for White Pine was considerably lower than that for the Southern Yellow Pine. A sample force-displacement graph is shown below in Figure 5. A photograph of the post fracture for test WP-4 is provided in Figure 6.

The average peak force for White Pine was 37.6 kN (8.5 kips), with a standard deviation of 8.0 kN (1.8 kips). The maximum peak force was 57.2 kN (12.9 kips) and the minimum peak force was 13.6 kN (3.1 kips). The average energy dissipated at rupture was 3.02 kJ (26.8 kip-in.), with a standard deviation of 1.33 kJ (11.8 kip-in.). Deflection at rupture averaged 351 mm (13.8 in.), with a standard deviation of 64 mm (2.5 in.).

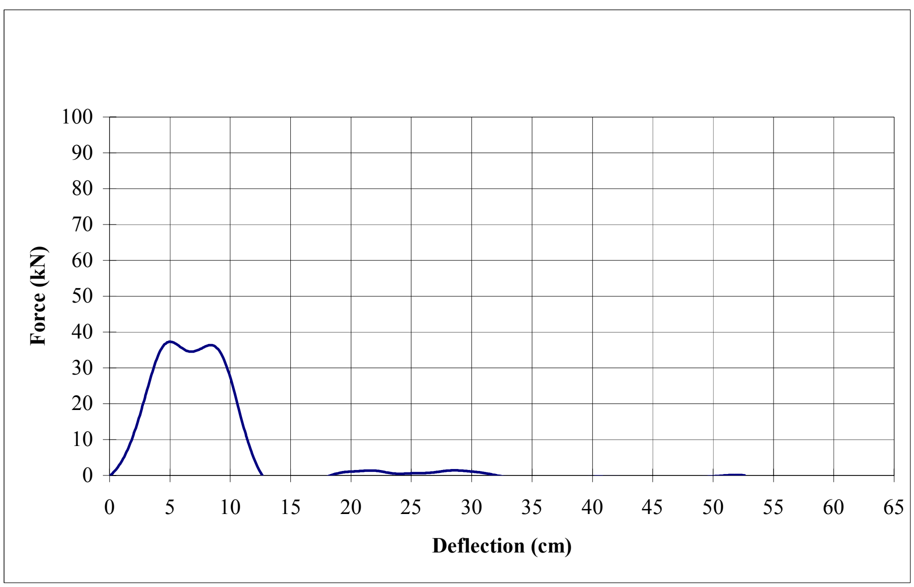


Figure 5. WP-4 Force- Deflection At Impact Location

Figure 6. WP-4 Fracture

5.2.2 Tests RP-1 through RP-30

The average peak force for the Red Pine posts was lower than that for Southern Yellow Pine. A sample force-displacement graph is shown below in Figure 7 along with a photograph of the fracture in Figure 8.

The average peak force for Red Pine was 53.9 kN (12.1 kips), with a standard deviation of 18.6 kN (4.2 kips). The maximum peak force was 95.3 kN (21.4 kips) and the minimum peak force was 31.2 kN (7.0 kips). The average energy dissipated at rupture was 4.75 kJ (42.0 kip-in.), with a standard deviation of 1.83 kJ (16.2 kip-in.). Deflection at rupture averaged 360 mm (14.2 in.), with a standard deviation of 83 mm (3.3 in.).

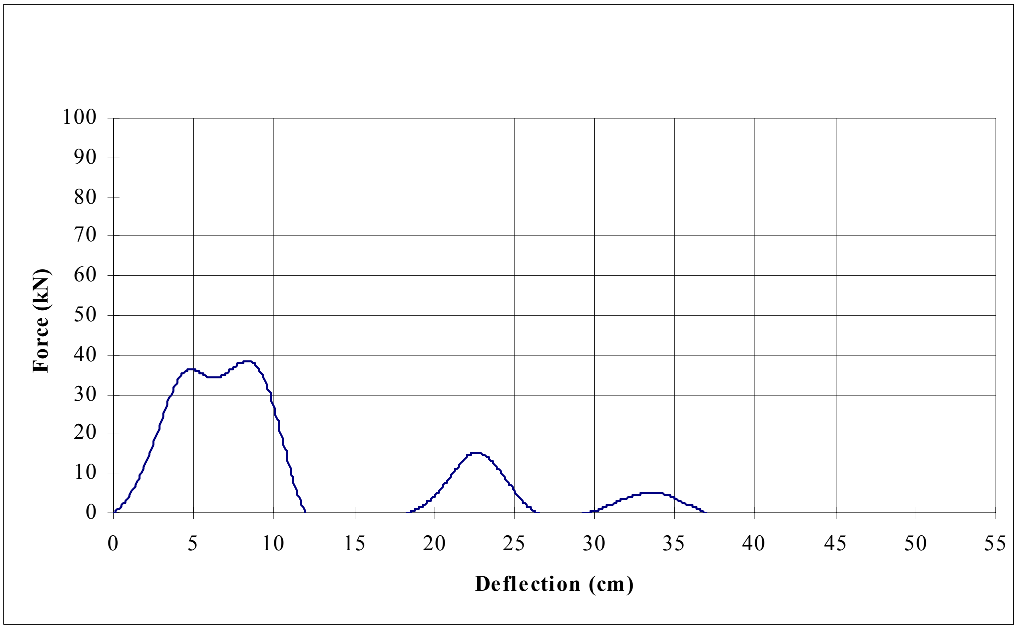


Figure 7. RP-27 Force-Deflection At Impact Location

Figure 8. RP-27 Fracture

6 DISCUSSION ON POST SIZE

The performance of a W-beam longitudinal barrier is largely based on the rotation of the posts embedded in the soil. This energy absorption is critical for both limiting the tensile stress in the guardrail element and minimizing the chances for vehicle instability. To define acceptable performance for utilizing alternative wood species as posts in these systems, it is necessary that these alternatives have equivalent dynamic strength to assure that they will provide the same degree of energy absorption. Because the force required to rotate a post in soil is dependent on the width of the section, alternatives need to maintain this same width in order to eliminate the need for full-scale vehicle crash testing. This means changing the cross-sectional depth of the post is the only way to increase the energy absorption.

To calculate a suggested depth, the assumption was made that the Wisconsin posts should provide the same resisting moment as the Southern Yellow Pine posts. Knowing the MOR value and the section modulus for Southern Yellow Pine posts, it is possible to calculate the resisting moment created by the posts. From the resisting moment, the MOR value for the Wisconsin posts can be used to solve for an equivalent section modulus and using the equivalent section modulus, a new depth can be found. The formulas used to calculate the suggested depth are shown in Equations 1 through 6, where b is cross-sectional width, d is cross-sectional depth, and S is the section modulus for the post.

$$MOR_{SYP} \times S_{X-SYP} = MOR_{n} \times S_{X-n} \qquad \text{(Equation 1)}$$

$$S_{X-n} = \frac{MOR_{SYP} \times S_{X-SYP}}{MOR_{X-n}} \qquad \text{(Equation 2)}$$

$$S_{X-n} = \frac{bd^2}{6} = \frac{(6in.)(d_n{}^2)}{6} = d_n{}^2 \qquad \text{(Equation 3)}$$

$$S_{X-SYP} = \frac{(6in.)(8in.)^2}{6} = 64in.^3 \qquad \text{(Equation 4)}$$

$$d^2 = \frac{MOR_{SYP} \times 64in.^3}{MOR_{X-n}} \qquad \text{(Equation 5)}$$

$$d = \sqrt{\frac{MOR_{SYP} \times 64in.^3}{MOR_{X-n}}} \qquad \text{(Equation 6)}$$

To find the equivalent depth of the post, several comparisons could be used, all of which result in slightly different conclusions. For the purpose of this study, two methods were considered. The first method was to use the average moisture-adjusted MOR from dynamic bogie test data to compare Southern Yellow Pine to White and Red Pine. Although limited by the small sample size, the test results offer insight into the affects of defects on each species. Using this method, and the MOR values from Table 6, Table 7, and Table 8, the equivalent depth was found to be 226 mm (8.9 in.) for Red Pine and 257 mm (10.1 in.) for White Pine.

The second method compares average, tabulated, saturated MOR values given in the Wood Handbook (5). These values are based on static test results of a much larger sample and should be considered more representative of the species as a whole. The downfall is that the given data is for clear specimen under static conditions rather than those with defects such as knots and splits under dynamic conditions. Using this method, the equivalent depth was found to be 239 mm (9.4 in.) for Red Pine and 262 mm (10.3 in.) for White Pine. The MOR values used for each species are displayed in Table 13.

Table 13. Wood Handbook MOR Values Given for Green Specimen in Static Bending

Species	Varieties	MOR MPa (ksi)	Average MOR MPa (ksi)
Red Pine	Red Pine	40.00 (5.8)	40.00 (5.800)
White Pine	Eastern White Pine	34.00 (4.9)	33.00 (4.800)
	Western White Pine	32.00 (4.7)	
Southern Yellow Pine	Loblolly	50.00 (7.3)	55.00 (7.975)
	Longleaf	59.00 (8.5)	
	Shortleaf	51.00 (7.4)	
	Slash	60.00 (8.7)	

7 CONCLUSIONS AND RECOMMENDATIONS

Based on the results herein, it is recommended that guardrail posts produced using Red Pine and White Pine should have increased section depths to compensate for their lower MOR's. The suggested depth is 238 mm (nominally 9 3/8 in.) for the Red Pine species and 264 mm (nominally 10 3/8 in.) for White Pine species. These sections, as shown in Table 14, will provide equivalent performance from Red and White Pine guardrail posts, without changing the soil reaction properties.

Table 14. Nominal Size Recommendations for White Pine and Red Pine

Species	Recommended Nominal Size	
	Depth mm (in.)	Width mm (in.)
Southern Yellow Pine	203 (8.000)	152 (6.000)
Red Pine	238 (9.375)	152 (6.000)
White Pine	264 (10.375)	152 (6.000)

8 REFERENCES

1. Rohde, J.R., Reid, J.D., and Sicking, D.L., *Evaluation of the Effect of Wood Quality on W-beam Guardrail Performance*, Transportation Research Report TRP-03-60-96, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 1995.

2. Powell, G.H., *BARRIER VII: A Computer Program For Evaluation of Automobile Barrier Systems*, Prepared for: Federal Highway Administration, Report No. FHWA RD-73-51, April 1973.

3. Evans, J.W., Evans, J.K, and Green, D.W., *Computer Programs for Adjusting the Mechanical Properties of 2-inch Dimension Lumber for Changes in Moisture Content*, General Technical Report FPL-GTR-63, United States Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, February 1990.

4. *Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens*, ASTM Standard No. D1990-00(2002)e1, ASTM International, April 2000.

5. Dietenberger, M.A., et al. *Wood Handbook – Wood as an Engineering Material*, Forest Products Laboratory, Forest Products Society, 1999.

Appendix A

A.1 Test Summary Information

A summary sheet for each test is provided in this section. Summary sheets include acceleration-time, velocity-time, displacement-time, force-deflection, and energy-deflection plots.

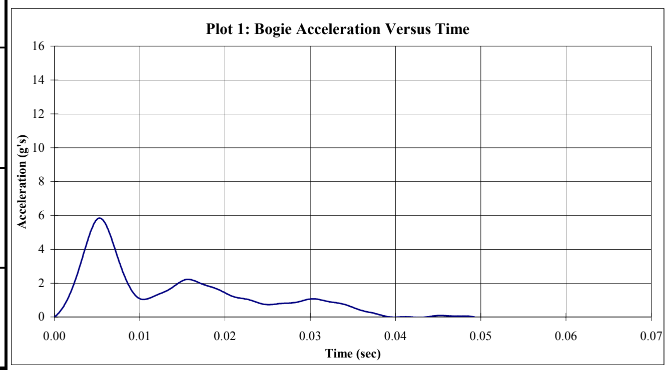
Table 15. Post Testing Summary

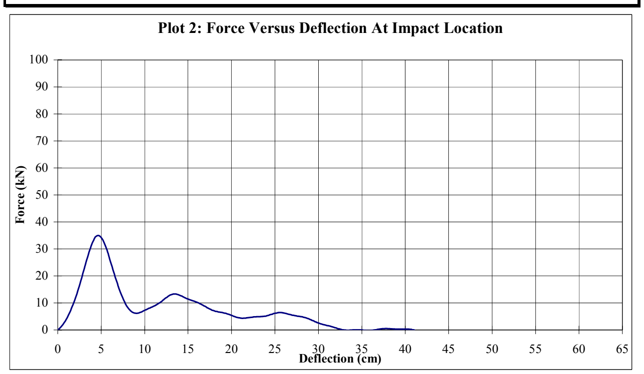
Test Parameters
Test: Strong Axis Impact at 0 degrees
Accelerometer: EDR-4 Data
Bogie Weight: 611 kg (1,346 lbs)
Bumper Height: 550 mm (21.65 in.)
Posts: 152 x 203 mm (6 x 8 in.)
Post Length: 1,829 mm (72 in.)

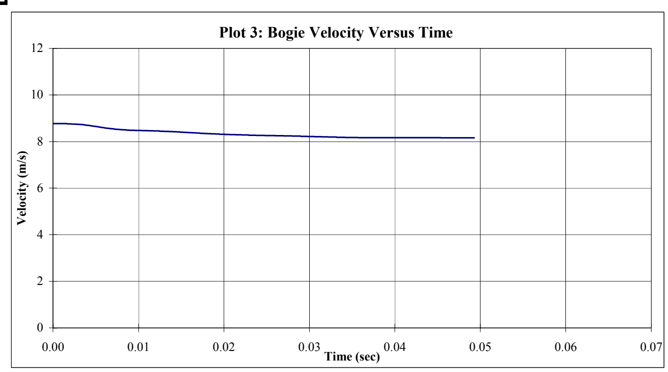
Midwest Roadside Safety Facility

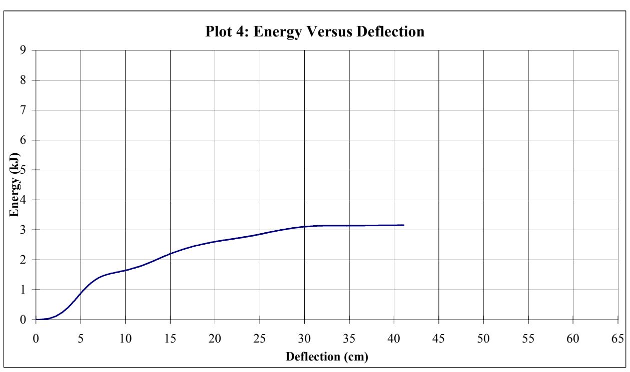
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-1		
Test Date:	30-Jun-2003		
Failure Type:	Very random splinters on fracture line, splinters are fairly short, break occurs at ground level		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.6 mph)	(28.8 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









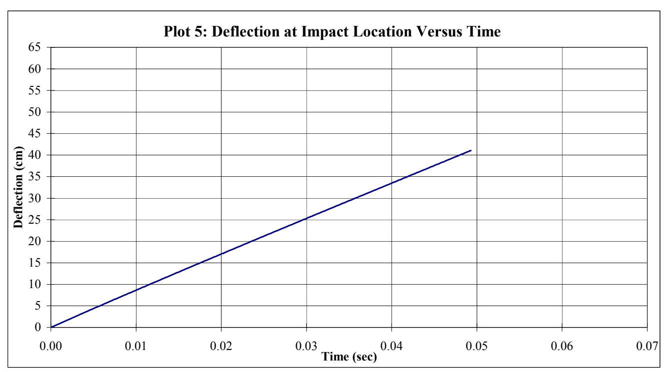
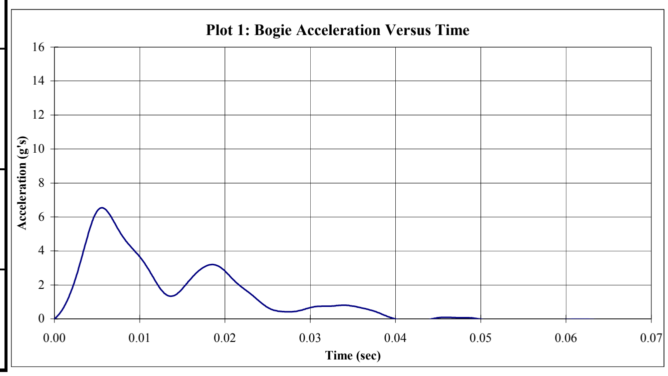
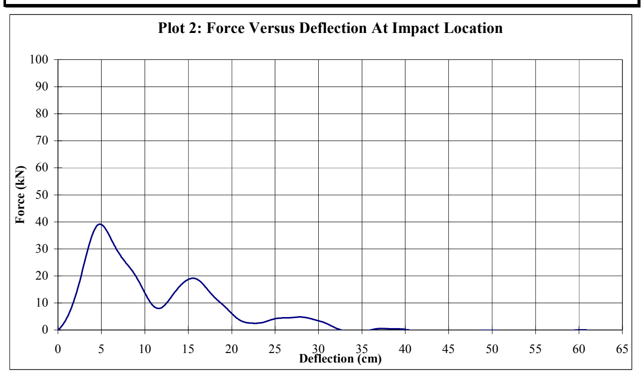


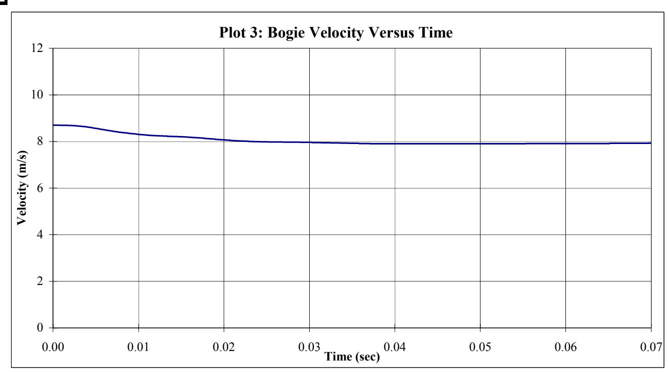
Figure 9. Results of WP-1

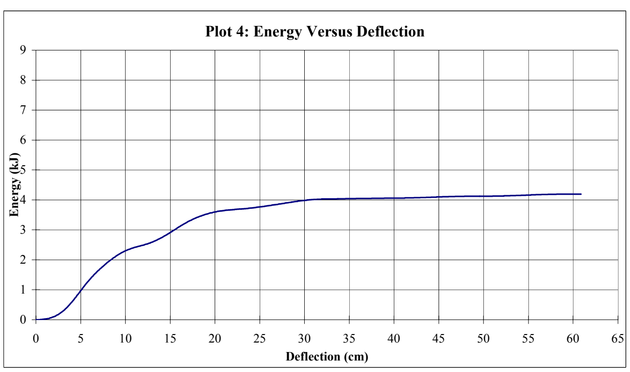
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-2		
Test Date:	30-Jun-2003		
Failure Type:	Fracture line is splintered somwhat randomly with longer splinters on leading and trailing edges, rings are very apparent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.5 mph)	(28.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









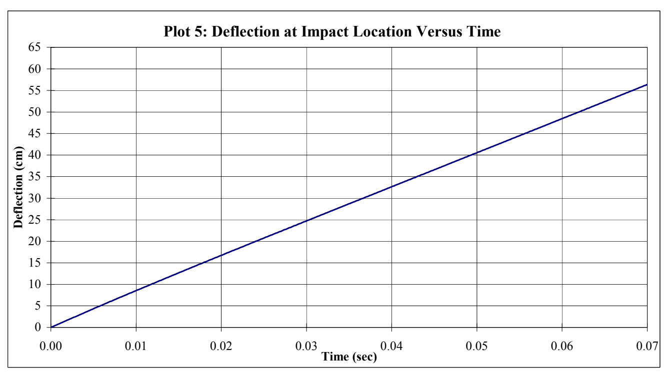
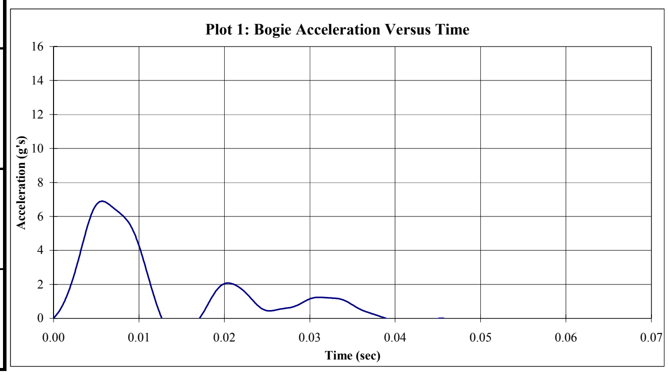
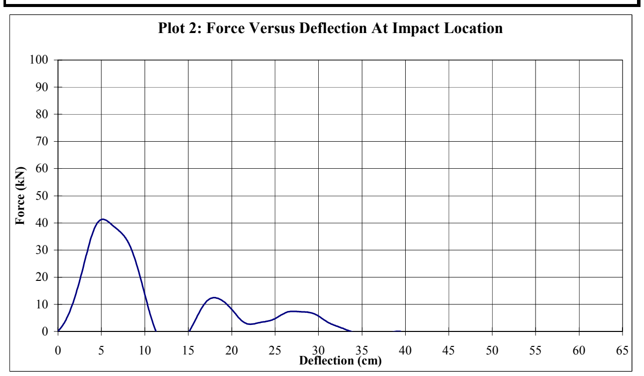


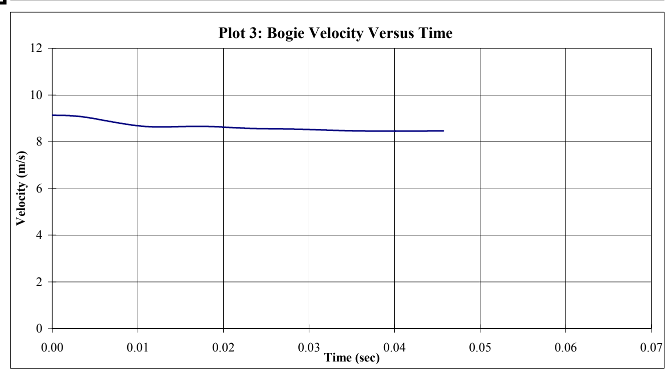
Figure 10. Results of WP-2

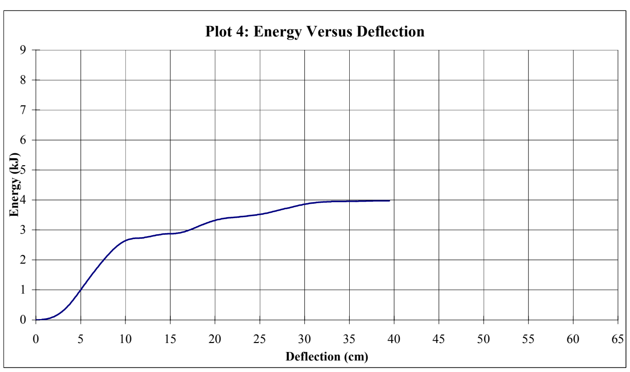
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-3		
Test Date:	30-Jun-2003		
Failure Type:	Short rough splinters with ring lines apparent in fracture, lon splinters on trailing edge of post		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.1 m/s	(20.4 mph)	(30.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









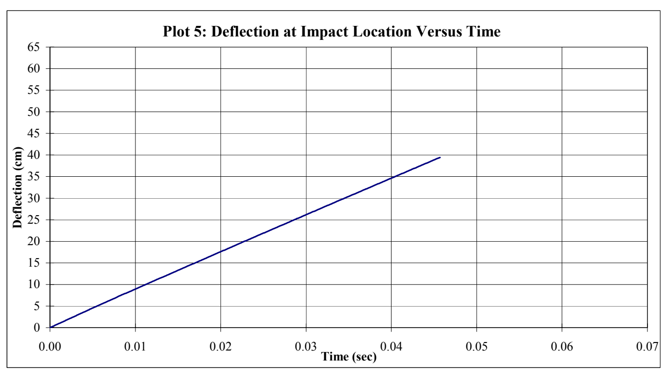
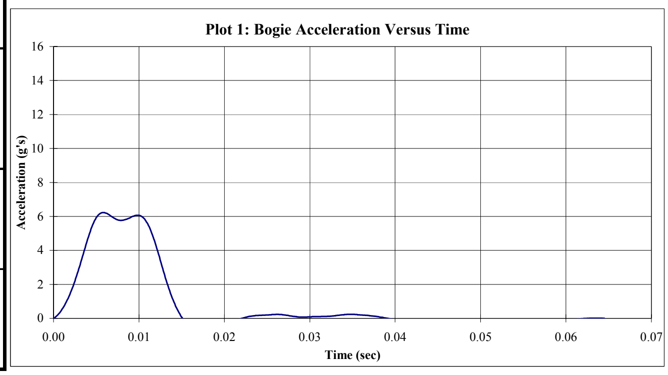
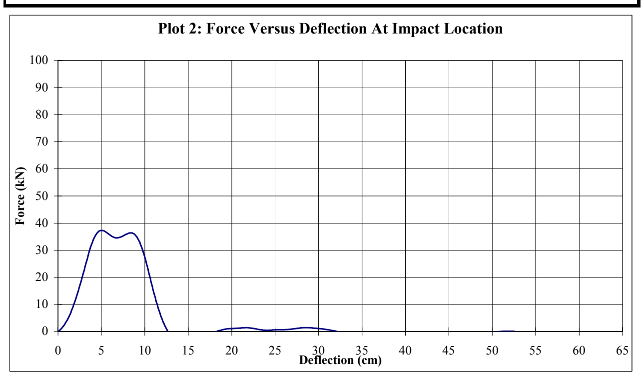


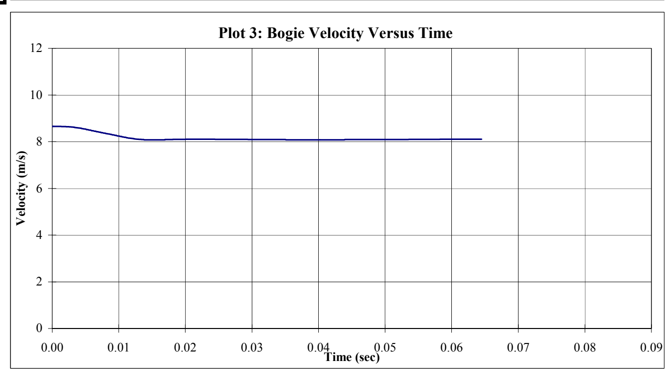
Figure 11. Results of WP-3

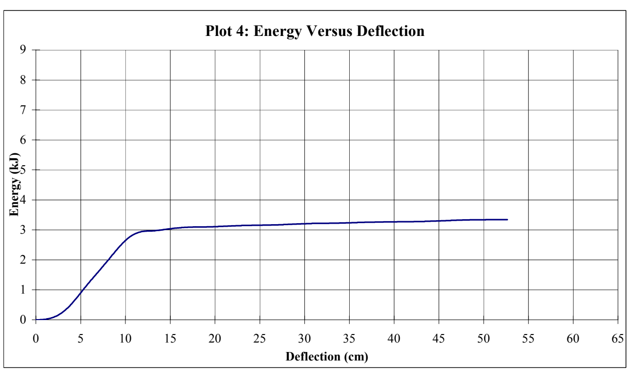
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-4		
Test Date:	30-Jun-2003		
Failure Type:	Rough splinters with ring pattern apparent, longer splinters noticed at edges of post, upper and lower sections attached		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.4 mph)	(28.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









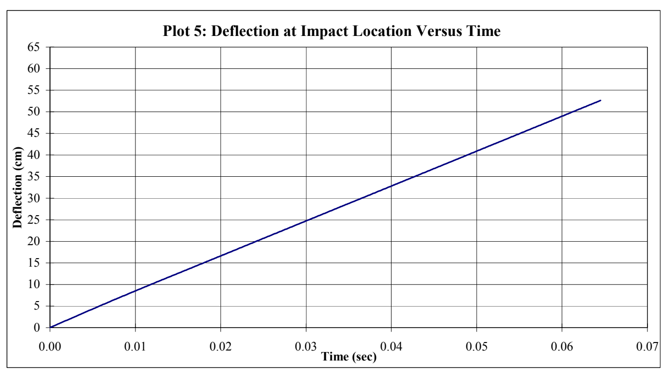
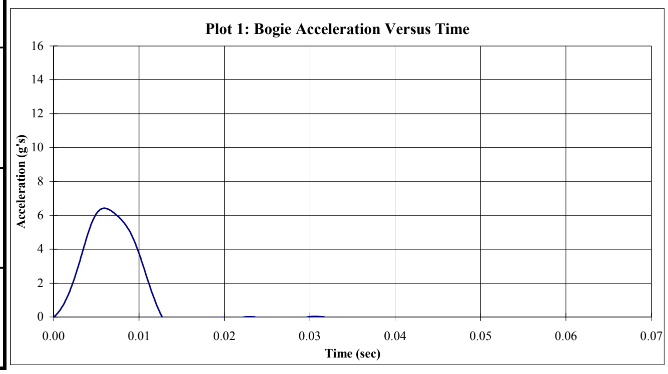
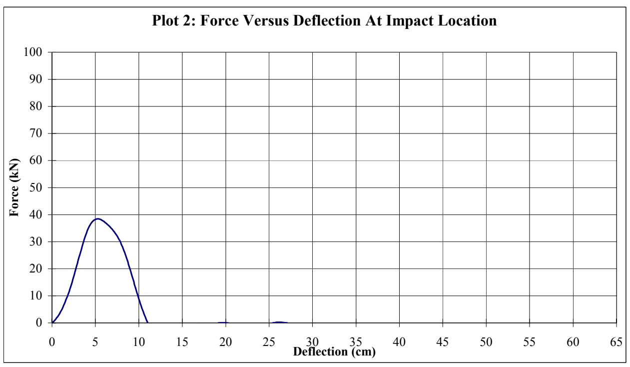


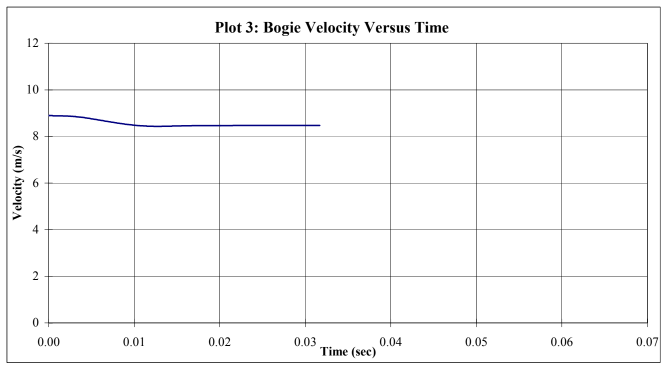
Figure 12. Results of WP-4

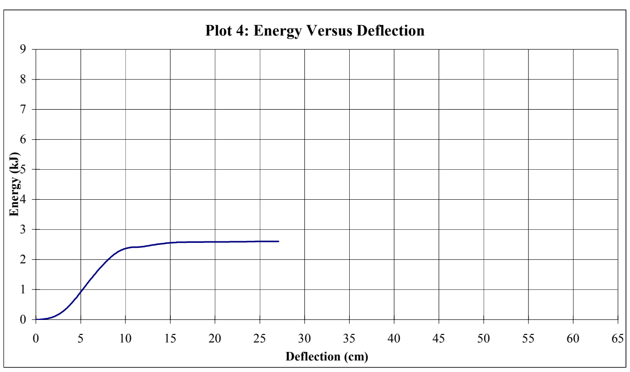
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-5		
Test Date:	30-Jun-2003		
Failure Type:	Short rough splinters, fracture at ground level, ring pattern very apparent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.9 mph)	(29.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









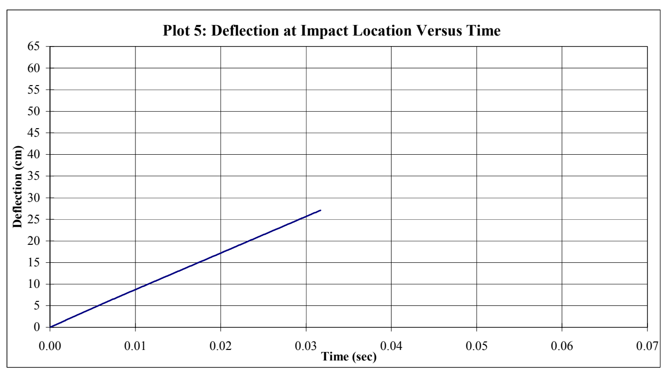
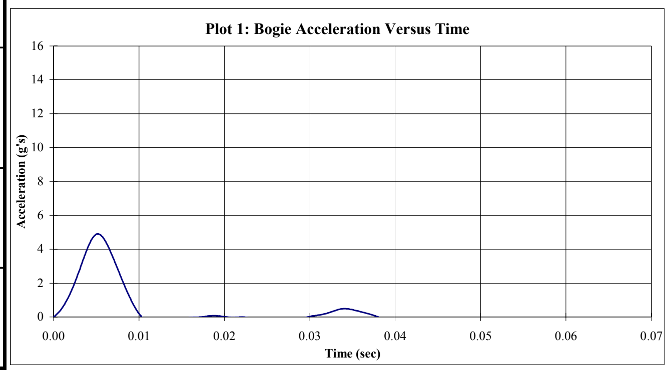
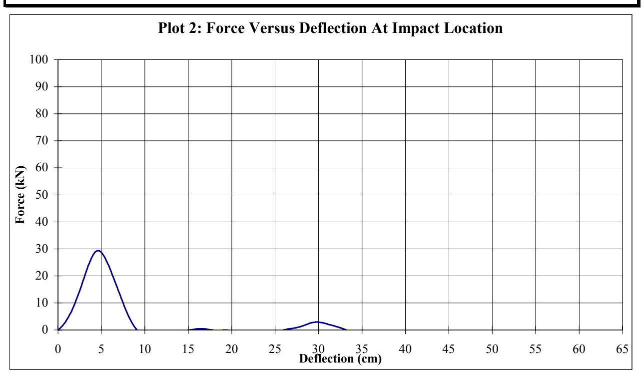


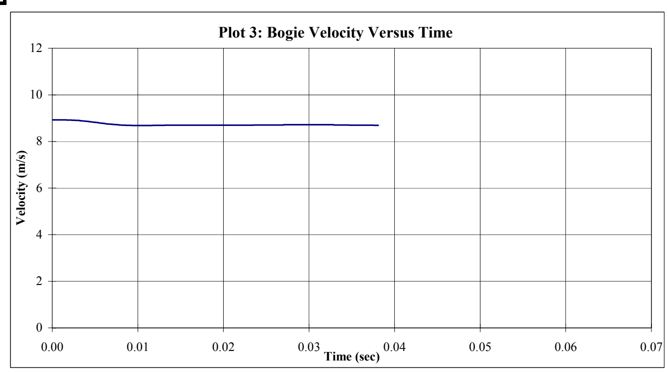
Figure 13. Results of WP-5

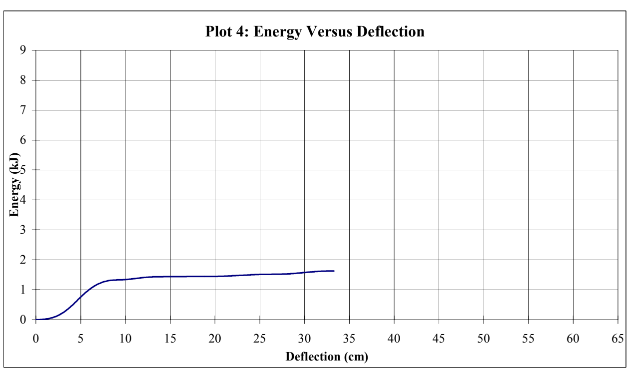
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-6		
Test Date:	30-Jun-2003		
Failure Type:			
	Rough surface with no major splinters, fracture line is sloped with leading edge higher than trailing edge		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









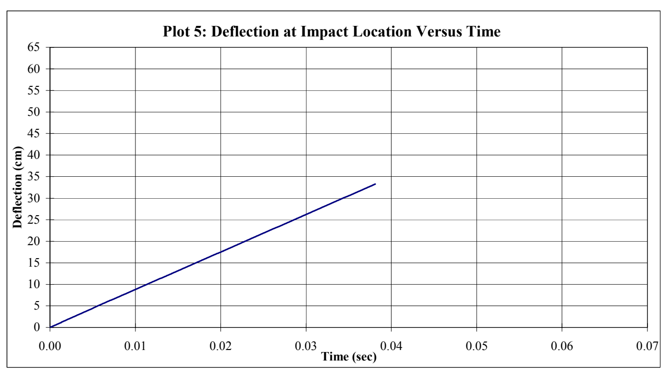
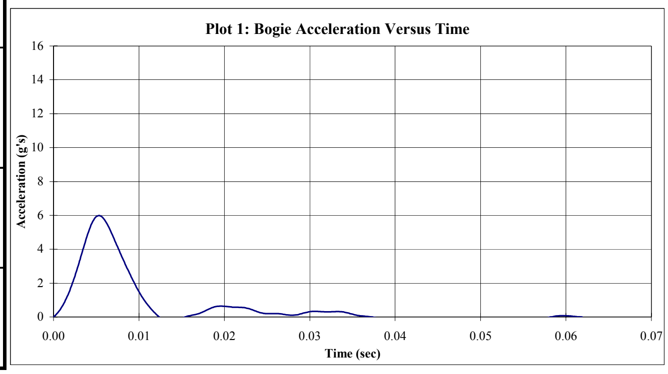
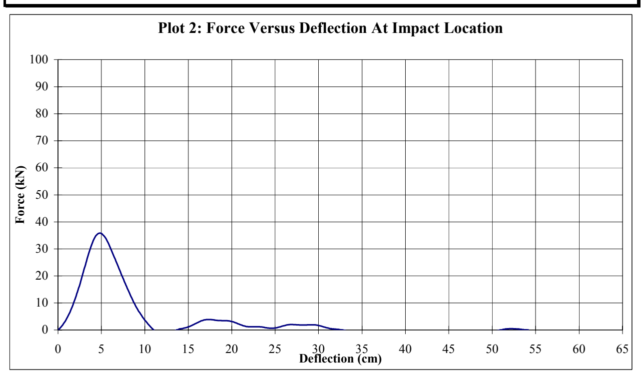


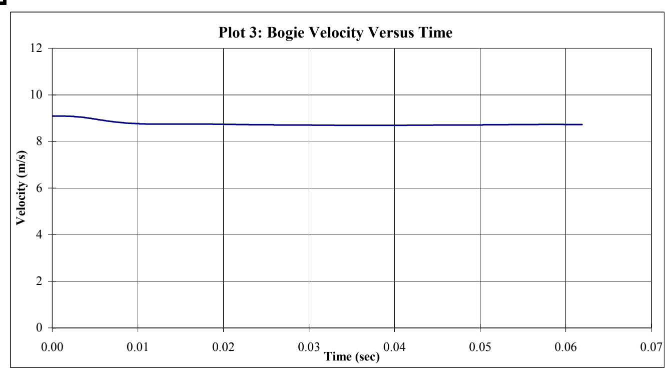
Figure 14. Results of WP-6

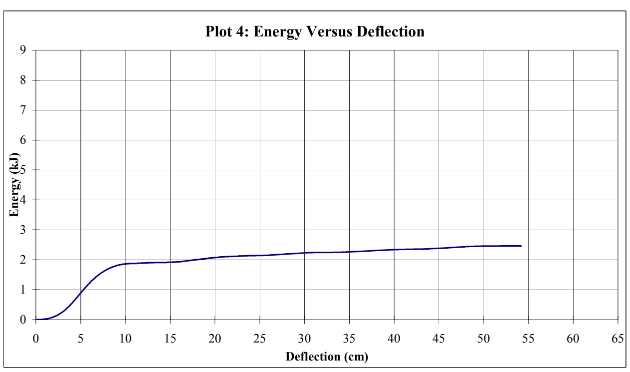
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-7		
Test Date:	30-Jun-2003		
Failure Type:	Very short jagged splinters, ring pattern is slightly apparent, long splinters on the trailing edge		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm metric		6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.1 m/s	(20.3 mph)	(29.8 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









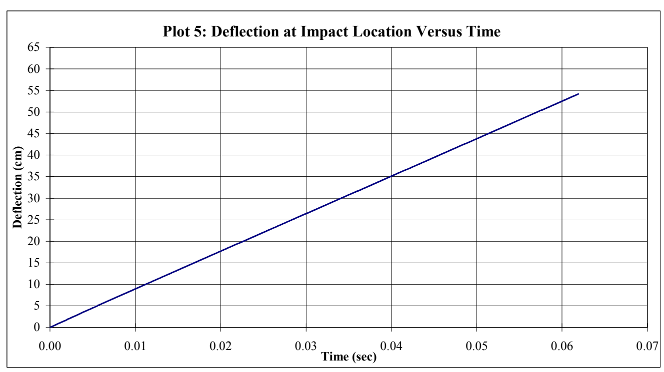
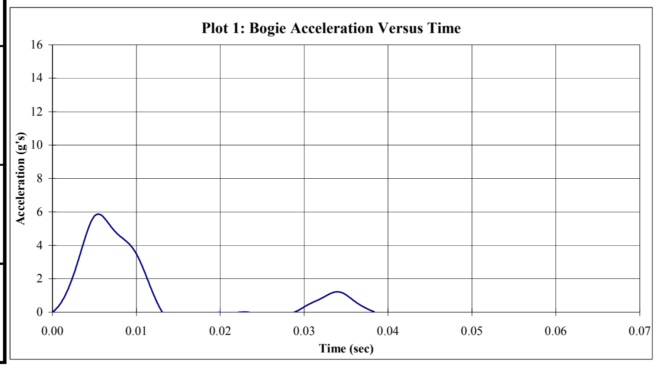
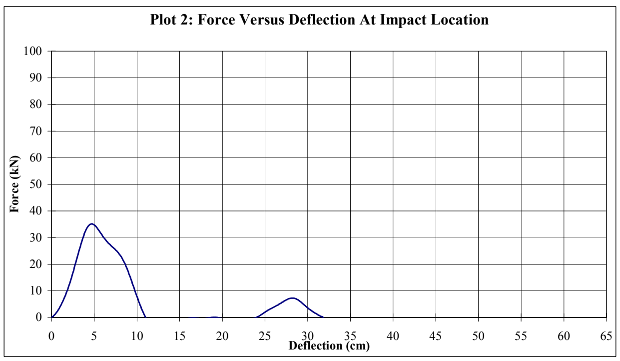


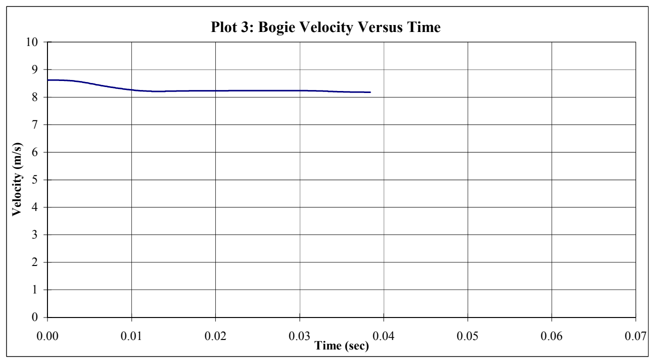
Figure 15. Results of WP-7

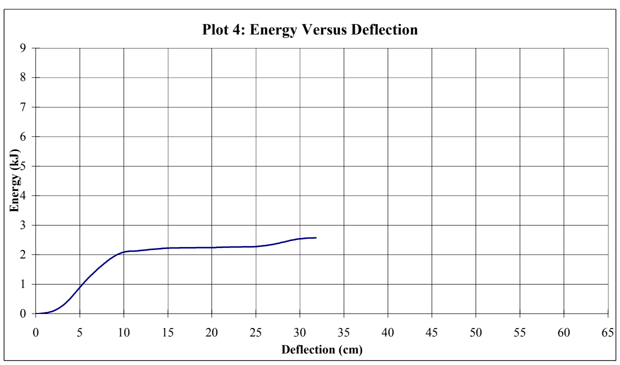
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees	
Test Number:	WISC WP-8	
Test Date:	30-Jun-2003	
Failure Type:	Random, short, jagged splinters on fracture line, break appears to be just below ground surface, ring lines are noticeable	
Post Properties		
Post Type:	Wisconsin White Pine	
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"
Post Length:	182.9 cm	(72.0 in)
Embedment Depth:	96.5 cm	(38.0 in)
Soil Properties		
Gradation:	Steel Sleeve	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m³	#VALUE!
Bogie Properties		
Impact Velocity:	8.6 m/s (19.3 mph)	(28.3 fps)
Impact Location:	55.0 cm (21.7 in)	above groundline
Bogie Mass:	611 kg (1346 lbf)	
Data Acquired		
Accelerometer Data:	EDR-4	
Camera Data:	Side View-Digital	









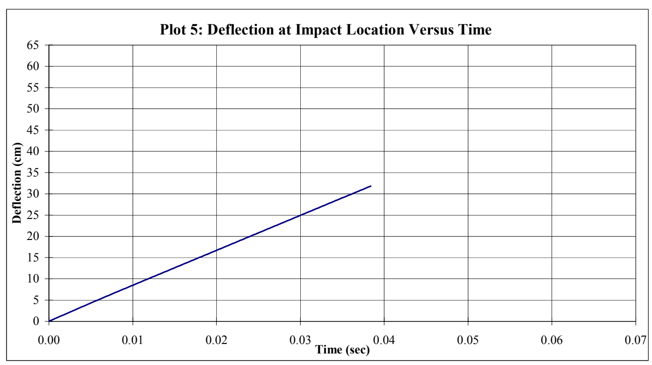
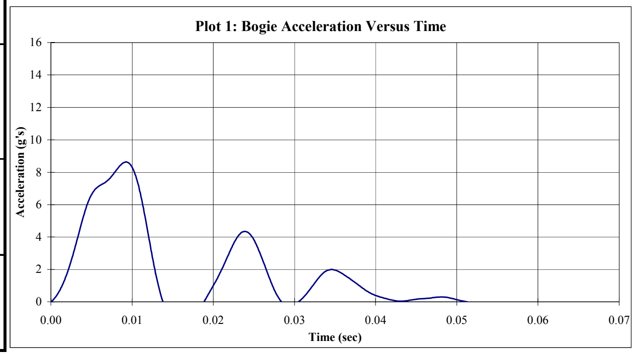


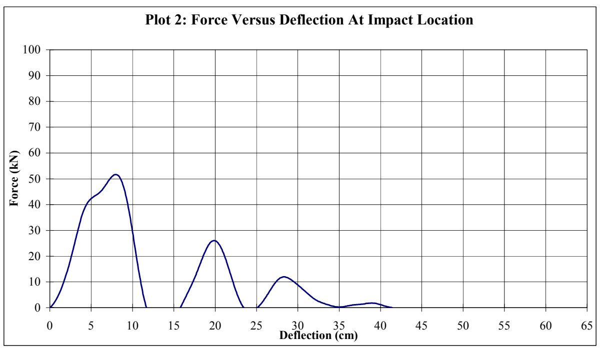
Figure 16. Results of WP-8

Midwest Roadside Safety Facility

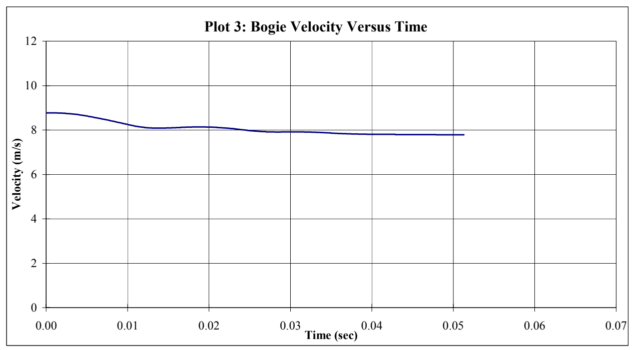
Bogie Test Summary			
Test Information		Deep Axis Impact @ 0 degrees	
	Test Number:	WISC WP-9	
	Test Date:	30-Jun-2003	
	Failure Type:	Fracture line is very jagged in sections, ring pattern is not as noticeable as other tests, impact side fracture is below ground	
Post Properties			
	Post Type:	Wisconsin White Pine	
	Post Size:	15.2 cm x 20.3 cm metric	6" x 8"
	Post Length:	182.9 cm	(72.0 in)
	Embedment Depth:	96.5 cm	(38.0 in)
Soil Properties			
	Gradation:	Steel Sleeve	
	Moisture Content:	NA	
	Compaction Method:	NA	
	Soil Density, γ_d:	NA kg/m³	#VALUE!
Bogie Properties			
	Impact Velocity:	8.8 m/s (19.6 mph)	(28.8 fps)
	Impact Location:	55.0 cm (21.7 in)	above groundline
	Bogie Mass:	611 kg (1346 lbf)	
Data Acquired			
	Accelerometer Data:	EDR-4	
	Camera Data:	Side View-Digital	



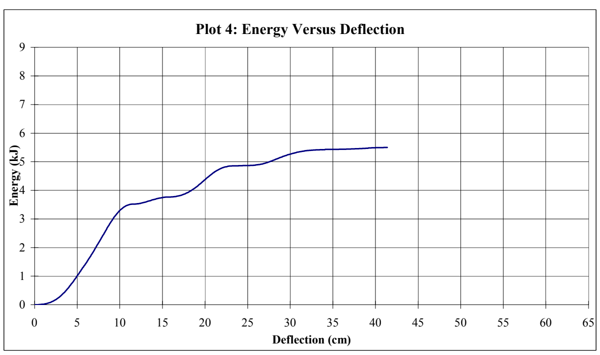
Plot 1: Bogie Acceleration Versus Time



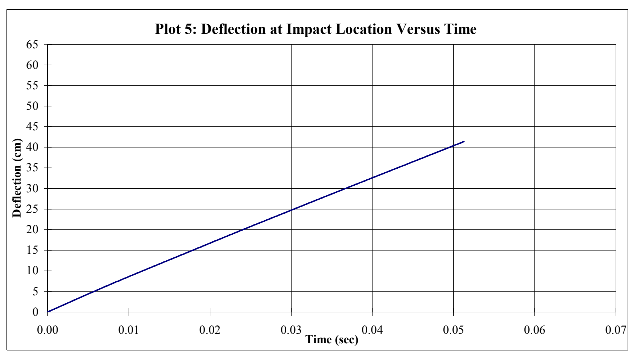
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

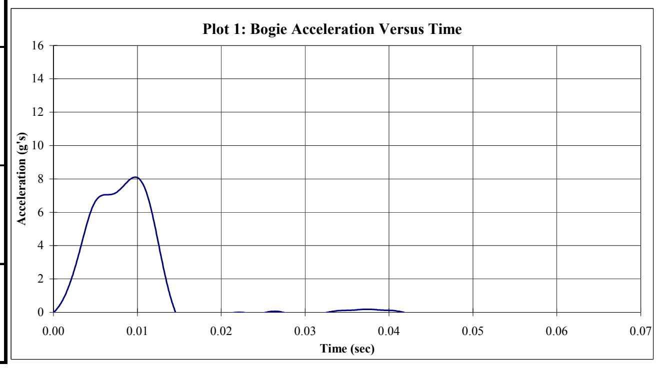


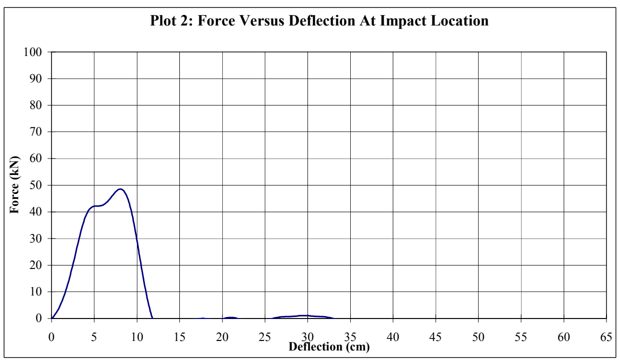
Plot 5: Deflection at Impact Location Versus Time

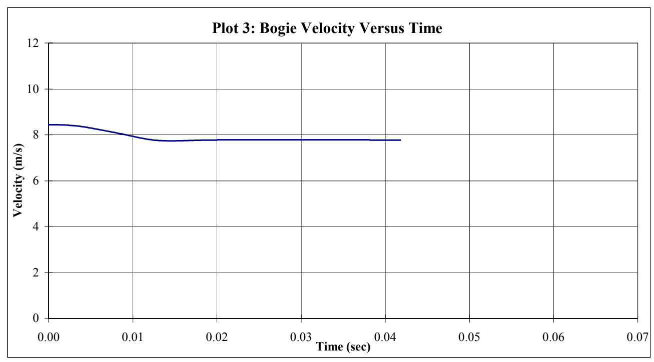
Figure 17. Results of WP-9

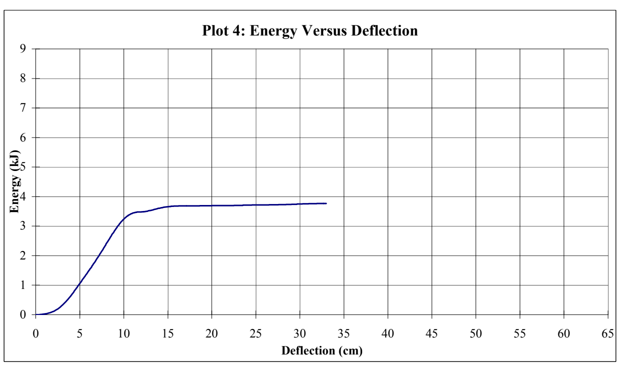
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-10		
Test Date:	30-Jun-2003		
Failure Type:	Very jagged fracture, random peaks, upper and lower sections connected, ring lines not as apparent, fracture at ground		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.4 m/s	(18.9 mph)	(27.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









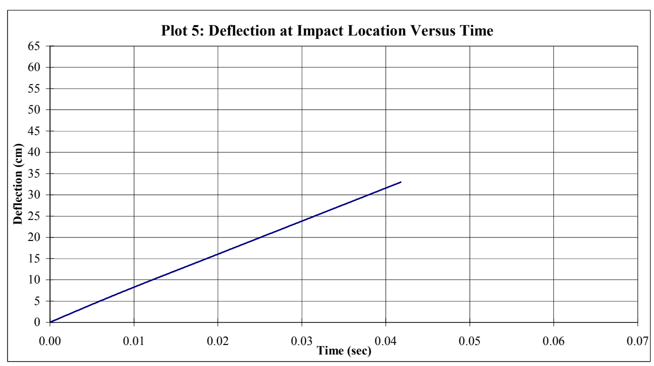
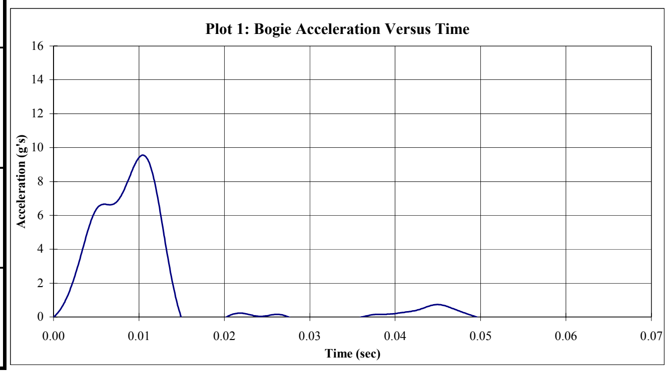
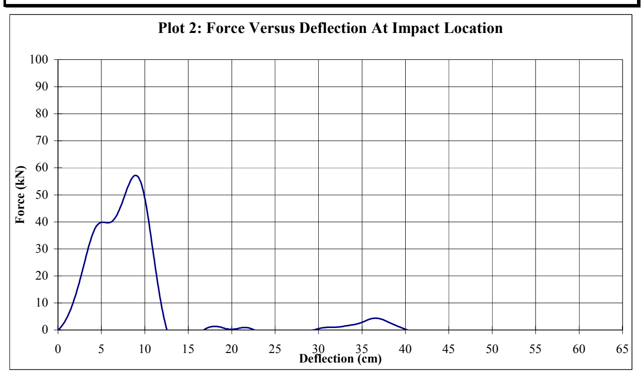


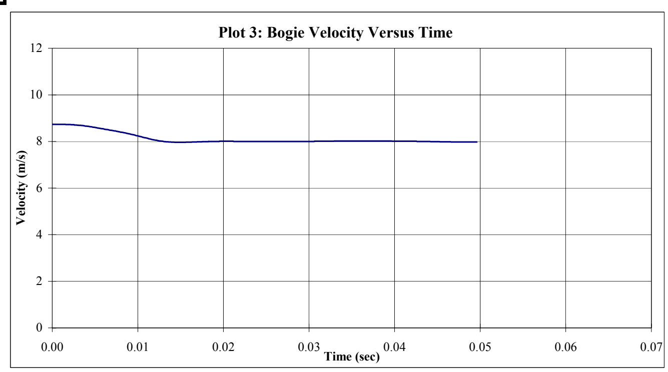
Figure 18. Results of WP-10

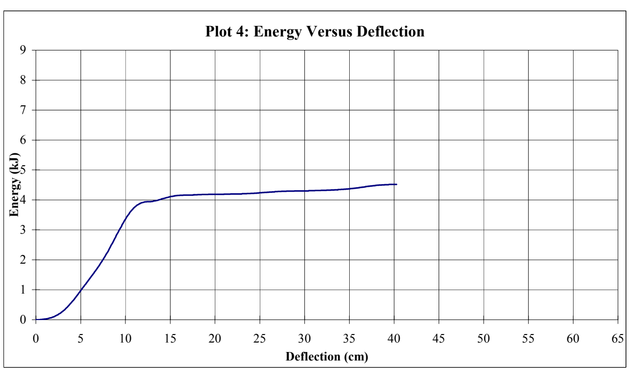
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-11		
Test Date:	30-Jun-2003		
Failure Type:	Fracture is conical with very defined ring lines, one long splinter, most are very short		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.5 mph)	(28.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









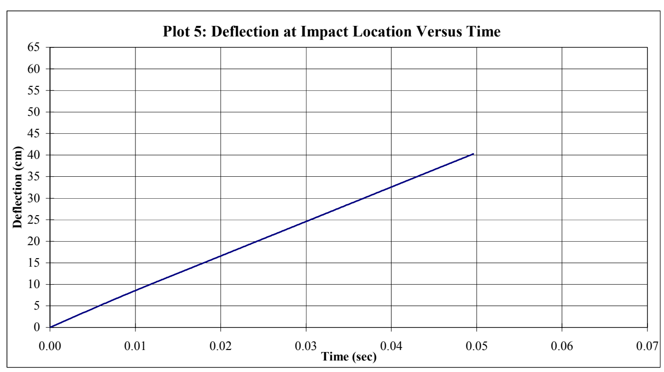
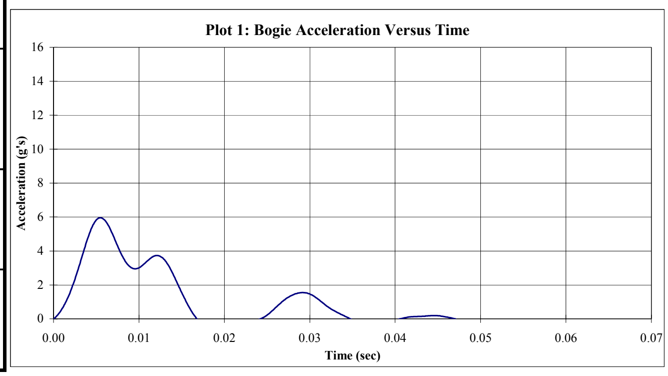
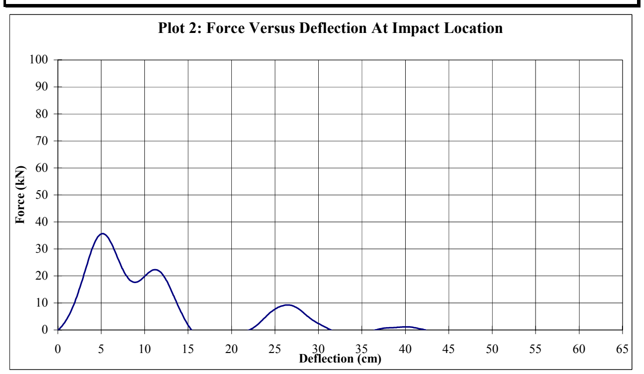


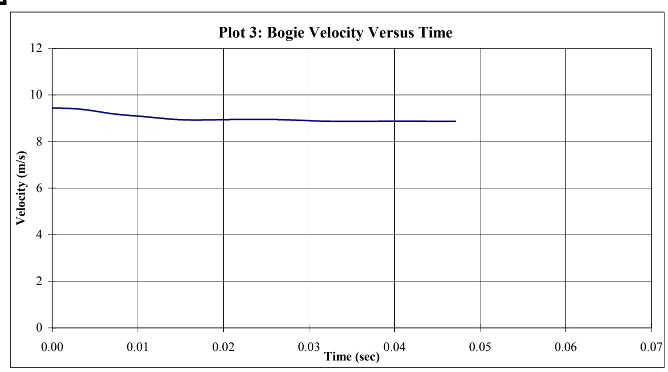
Figure 19. Results of WP-11

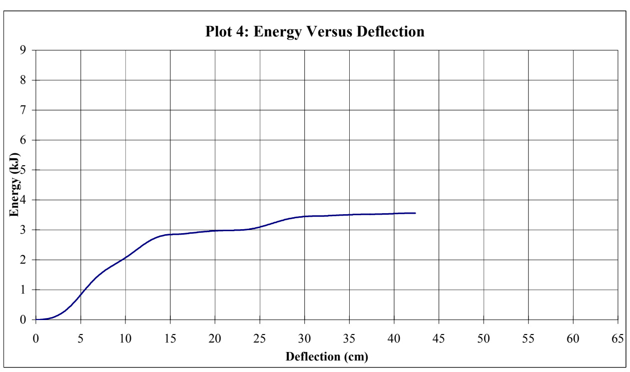
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-12		
Test Date:	30-Jun-2003		
Failure Type:	Random, short splinters on fracture line, break was below ground on impact side and at ground on trailing edge		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.4 m/s	(21.1 mph)	(31.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









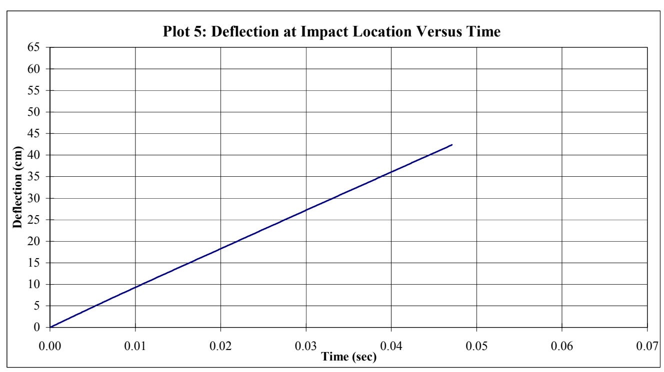
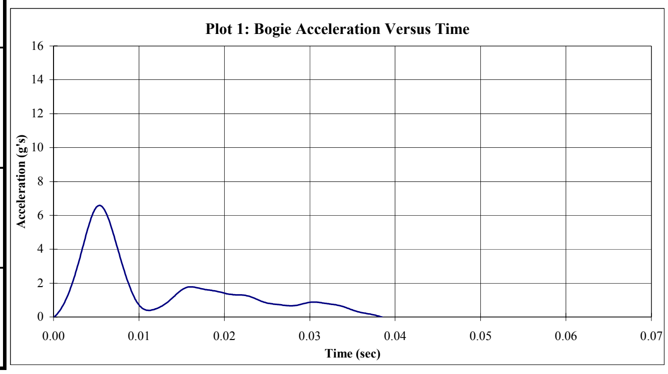
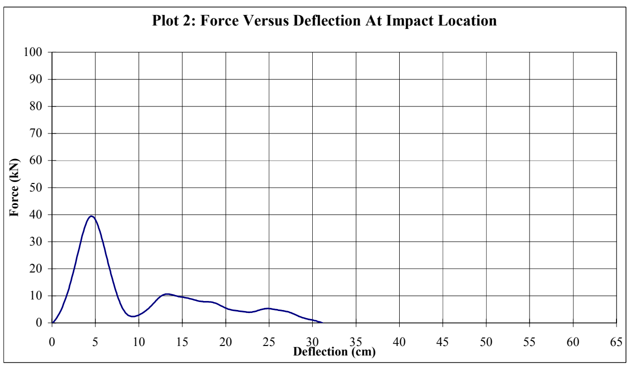


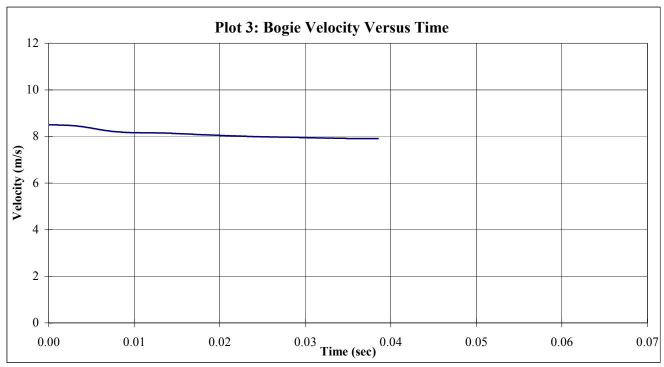
Figure 20. Results of WP-12

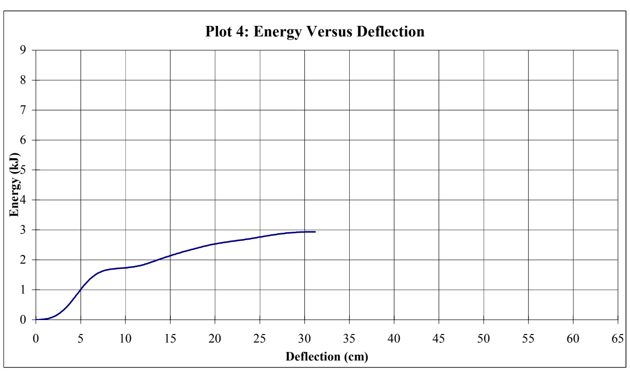
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-13		
Test Date:	30-Jun-2003		
Failure Type:			
	Jagged fracture line with random peaks, break is slightly below the ground surface		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.5 m/s	(19.0 mph)	(27.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









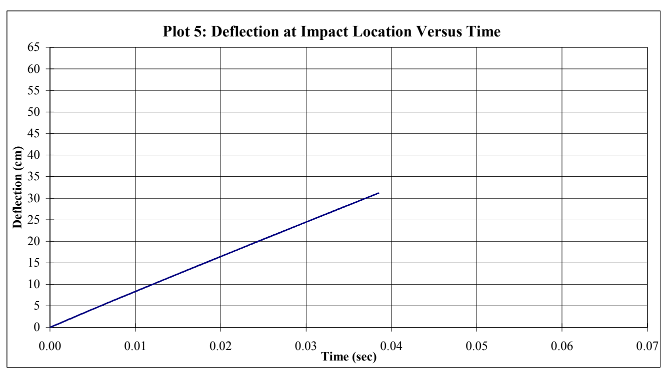
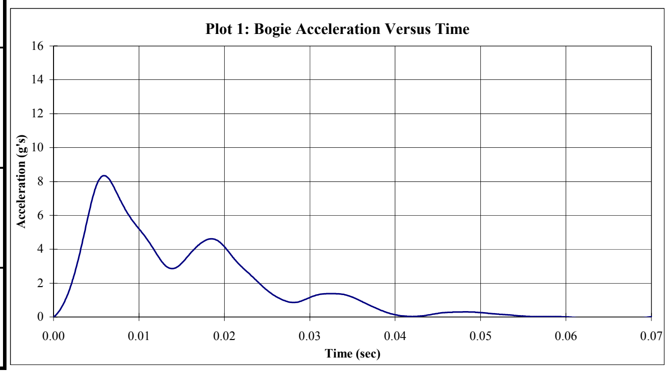
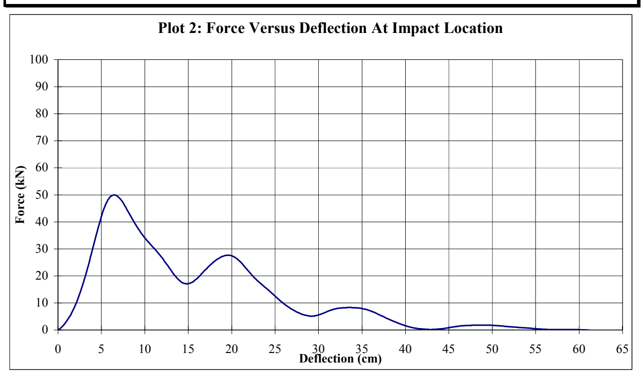


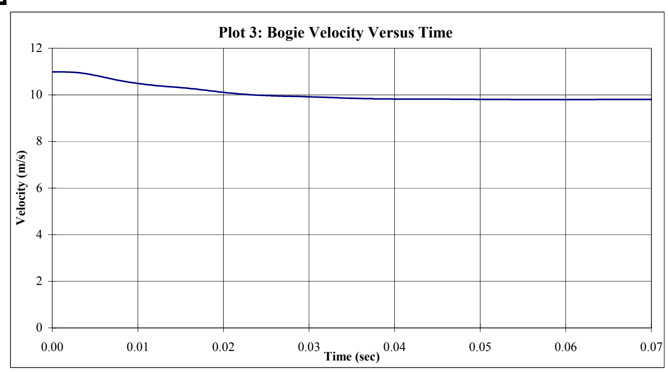
Figure 21. Results of WP-13

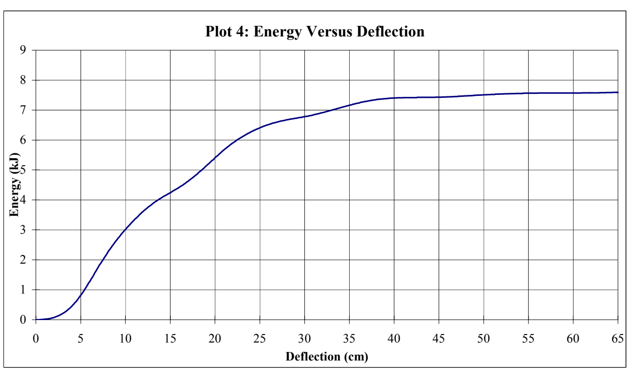
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-14		
Test Date:	30-Jun-2003		
Failure Type:	Sort, jagged splinters, impact side broke below ground surface trailing edge is at ground surface, fracture is on a slope		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	11.0 m/s	(24.6 mph)	(36.1 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









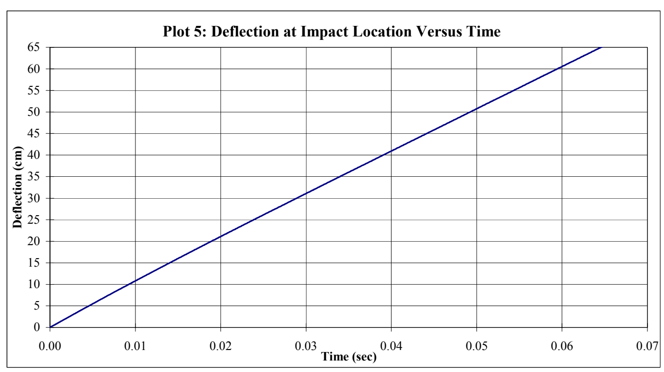
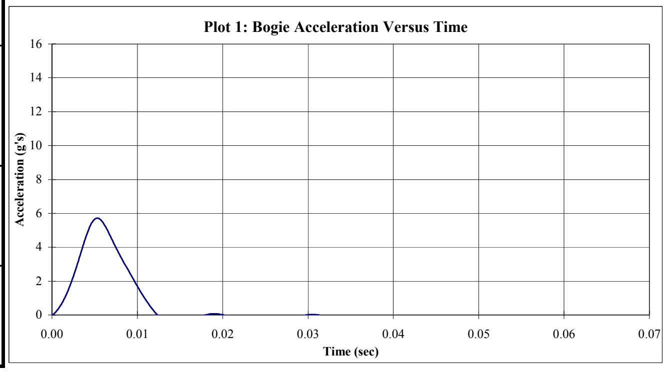
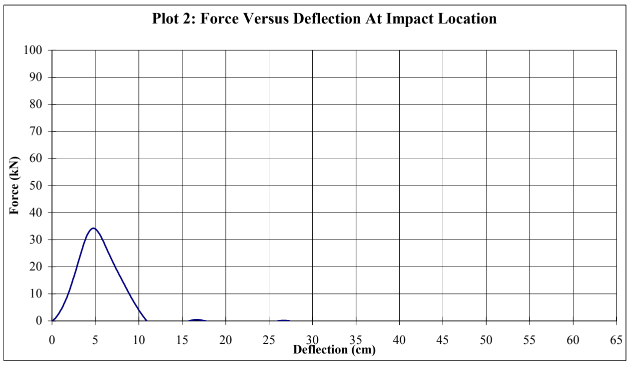


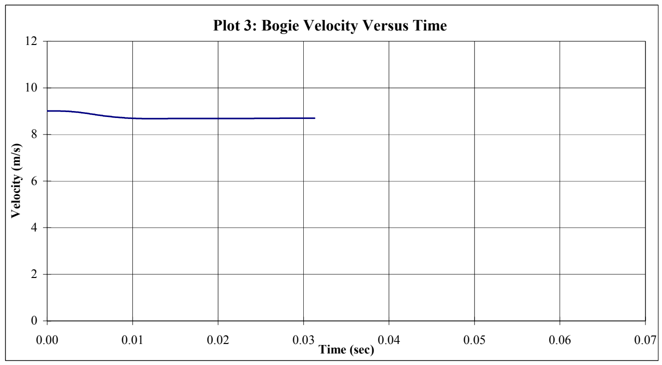
Figure 22. Results of WP-14

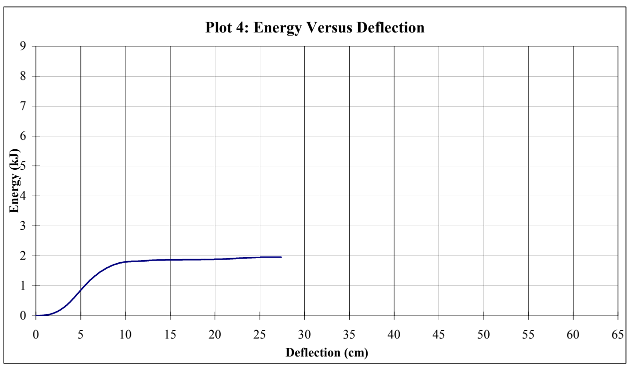
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-15		
Test Date:	30-Jun-2003		
Failure Type:	Very random fracutre line, short and long splinters with peaks on the impact face, ring lines are not very apparent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









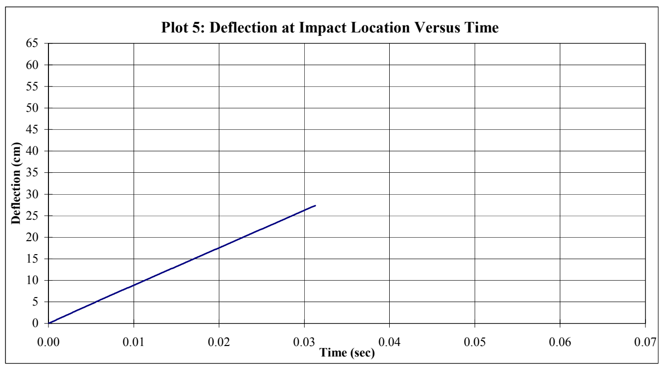
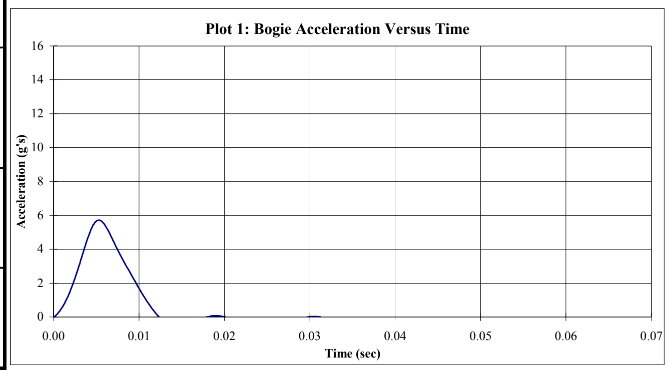
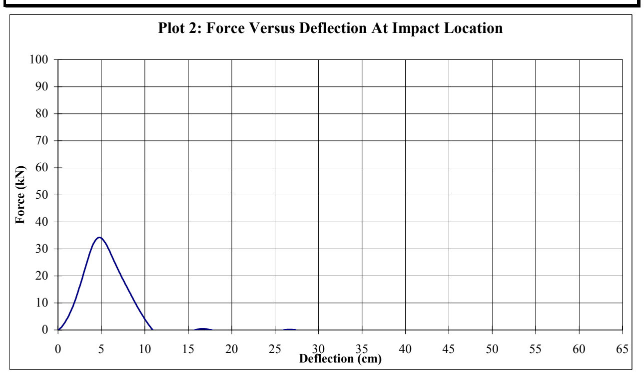
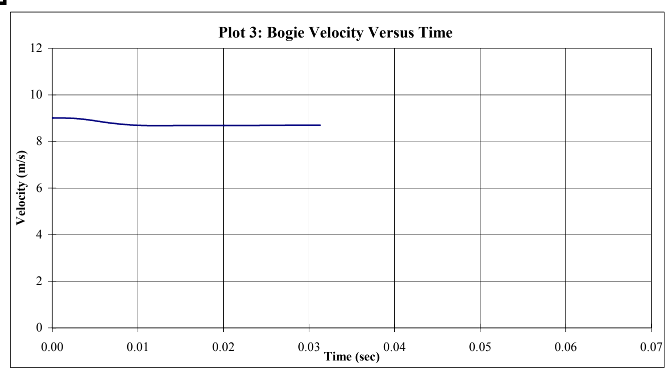


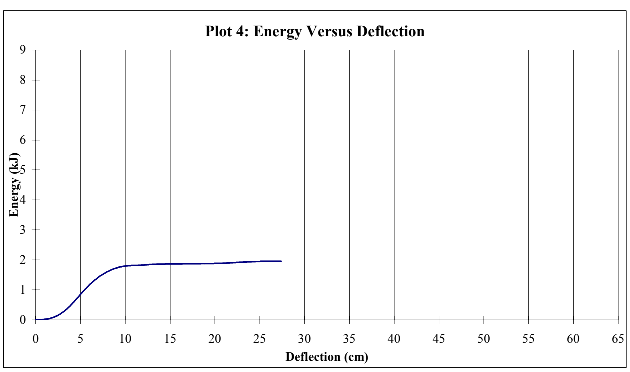
Figure 23. Results of WP-15

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-15		
Test Date:	30-Jun-2003		
Failure Type:	Very random fracutre line, short and long splinters with peaks on the impact face, ring lines are not very apparent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









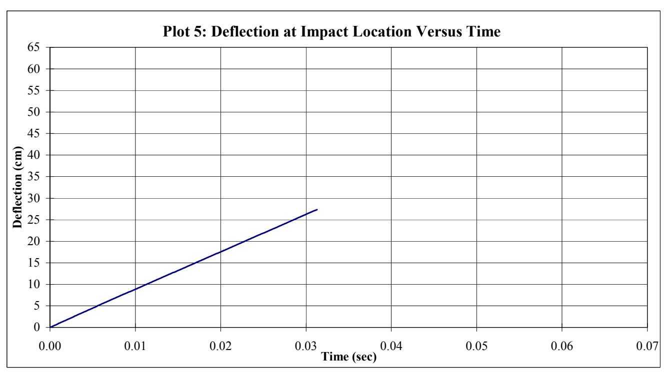
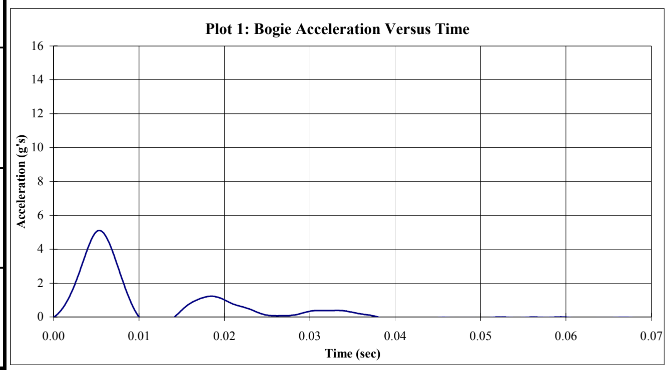
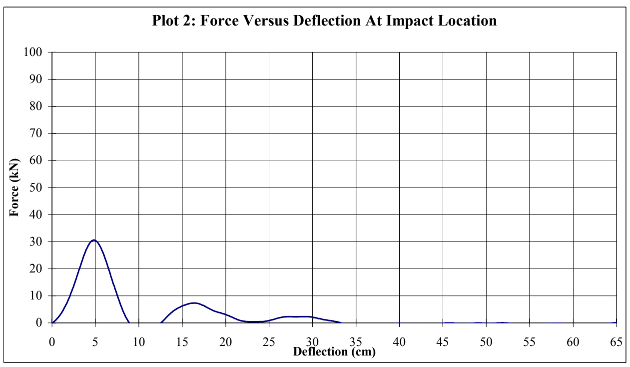


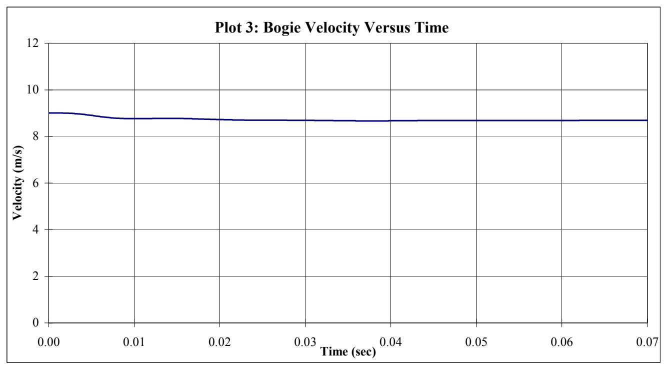
Figure 24. Results of WP-16

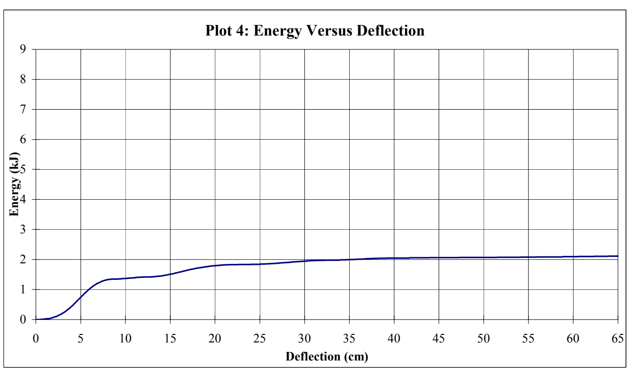
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-17		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line is very random, peaks and valleys are highly prevalent, splinters are small		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









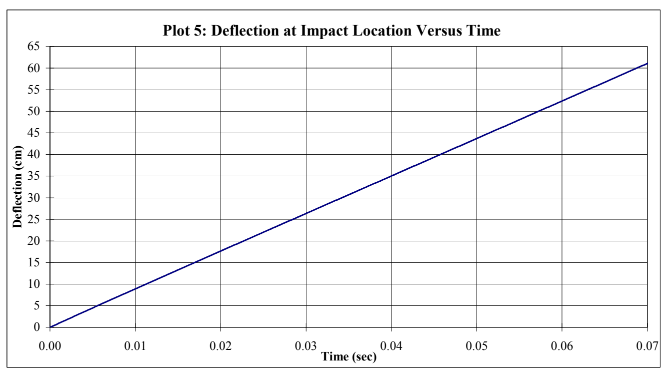
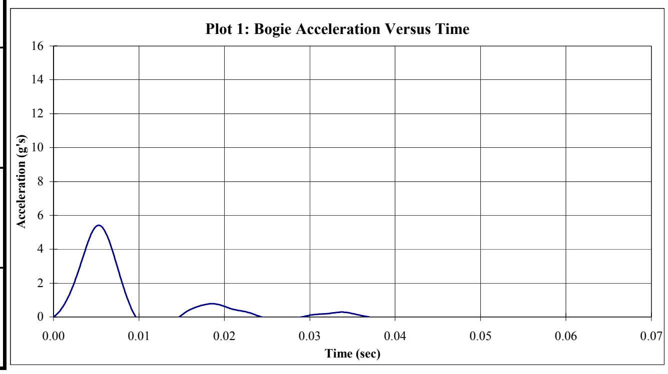
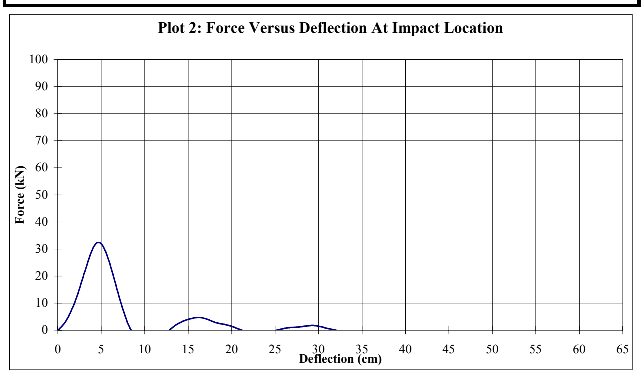
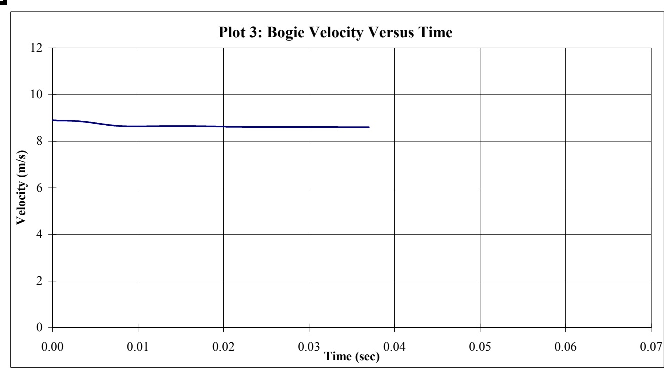


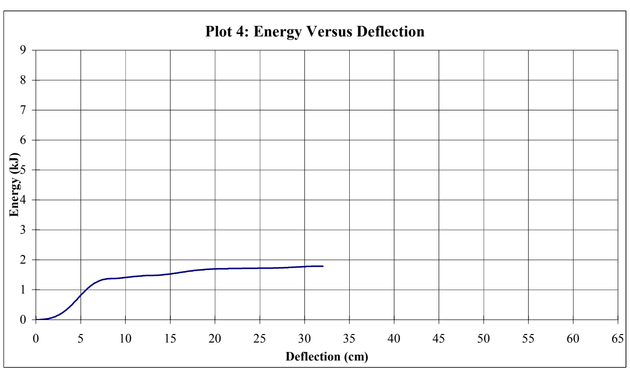
Figure 25. Results of WP-17

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-18		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line is fairly level with short splinters, ring lines apparent but not prominent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.9 mph)	(29.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









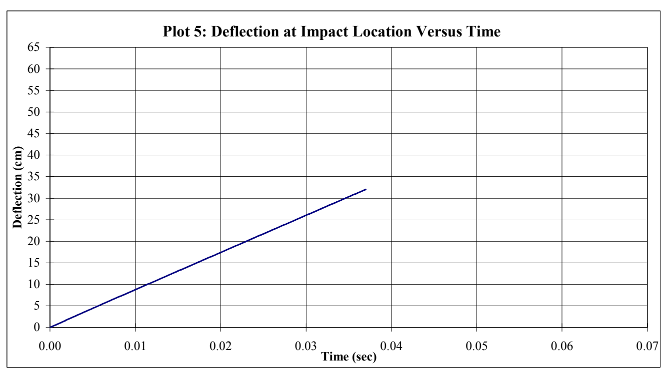
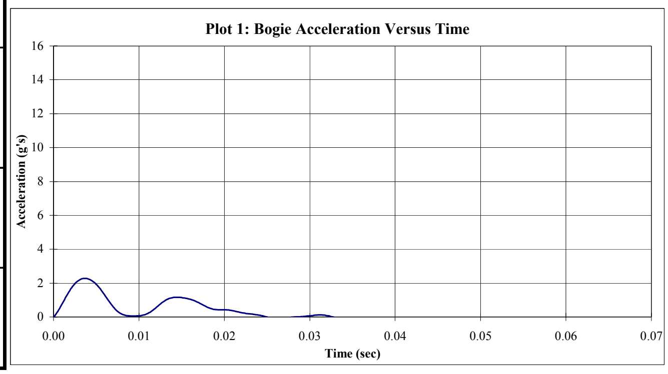
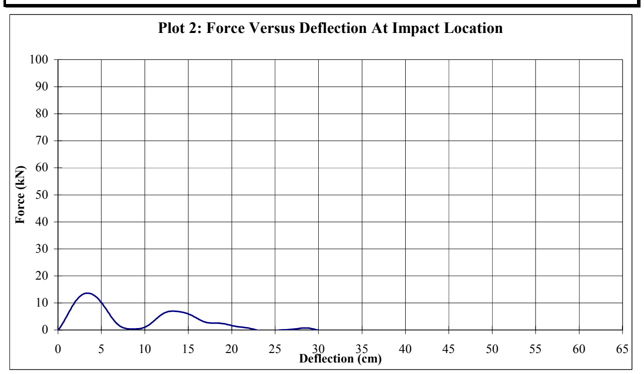


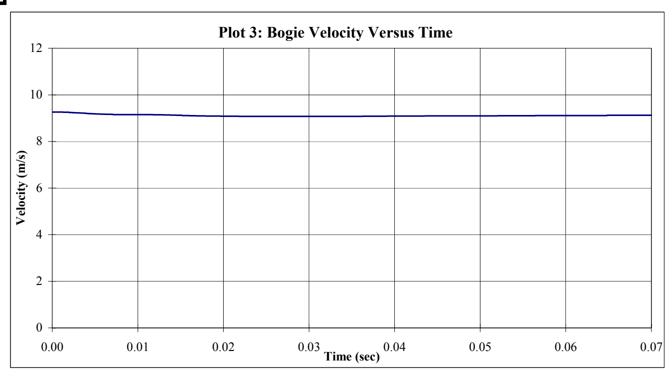
Figure 26. Results of WP-18

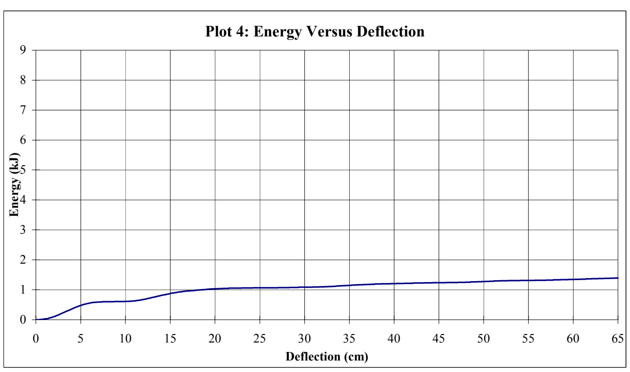
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-19		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line is fairly level and slightly below ground, break line has short rough splinters, ring lines apparent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.7 mph)	(30.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









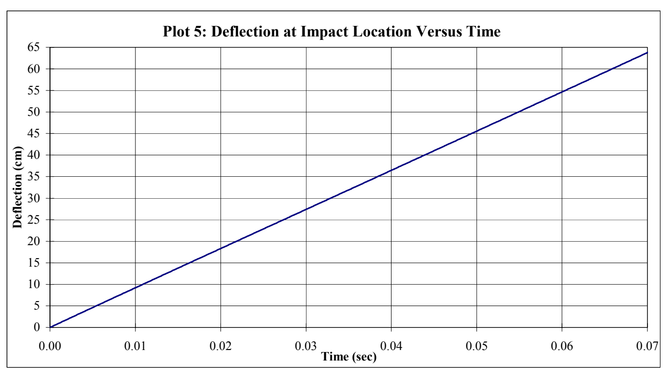
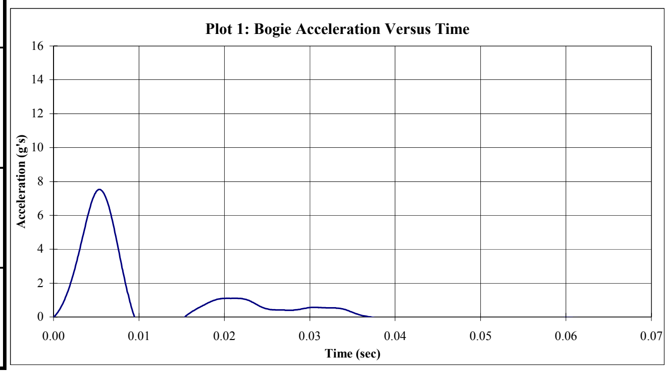
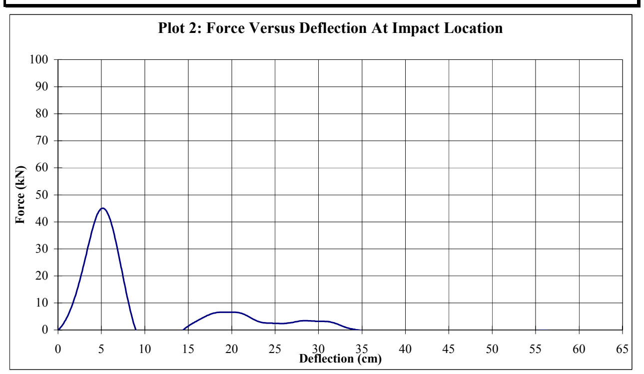


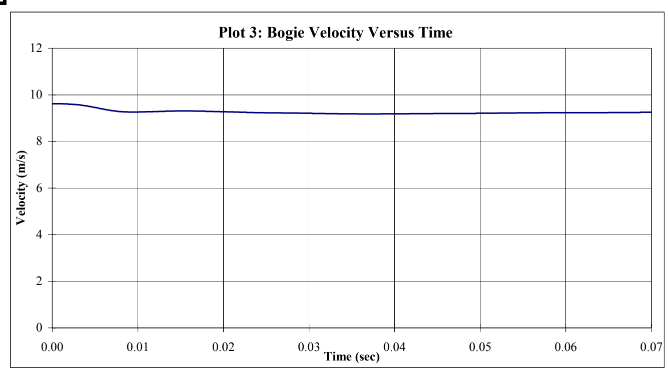
Figure 27. Results of WP-19

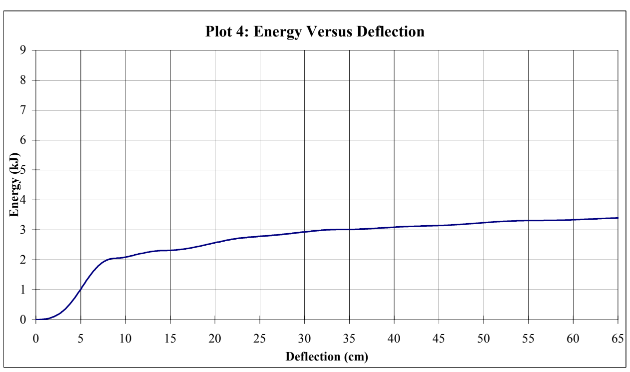
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-20		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line is low in impact side and high on opposite side, ring lines very apparent, rough short splinters		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.6 m/s	(21.5 mph)	(31.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









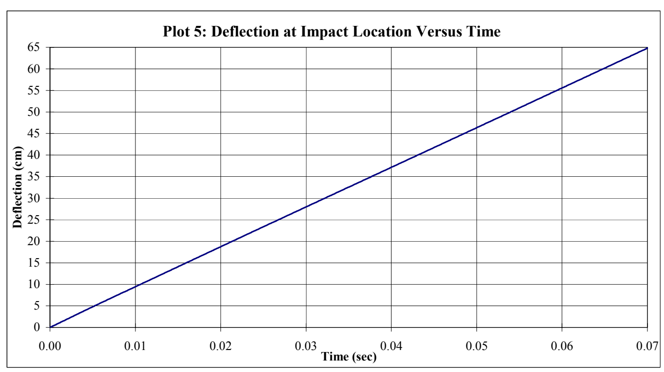
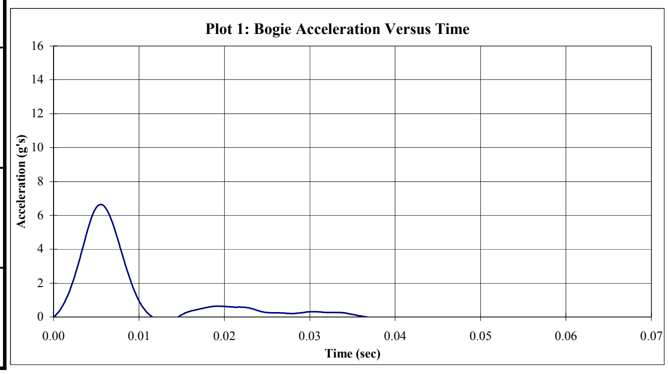
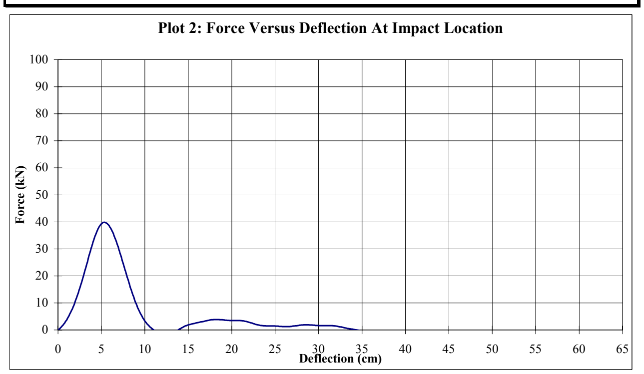
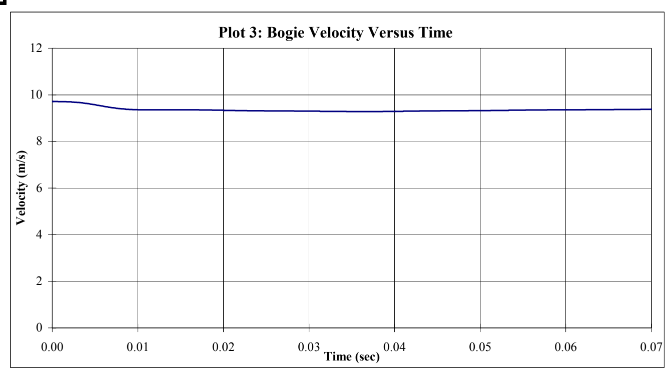


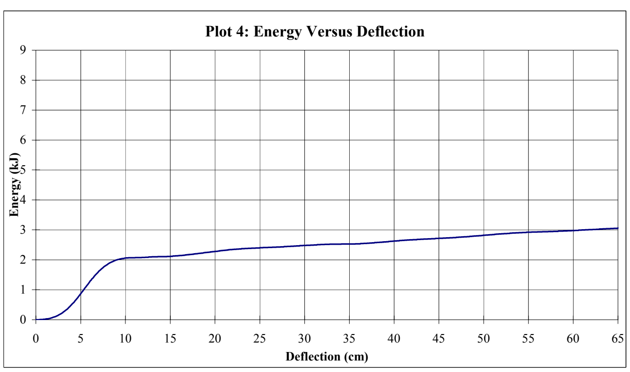
Figure 28. Results of WP-20

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-21		
Test Date:	27-Jun-2003		
Failure Type:	Very high peaks along the fracture line at the corners of the post, ring lines are apparent, short rough splinters		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.7 m/s	(21.7 mph)	(31.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









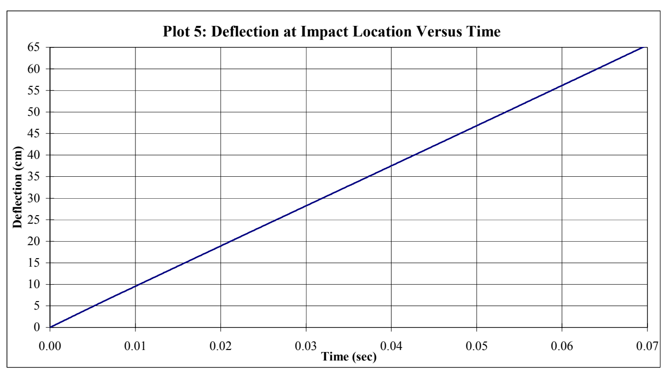
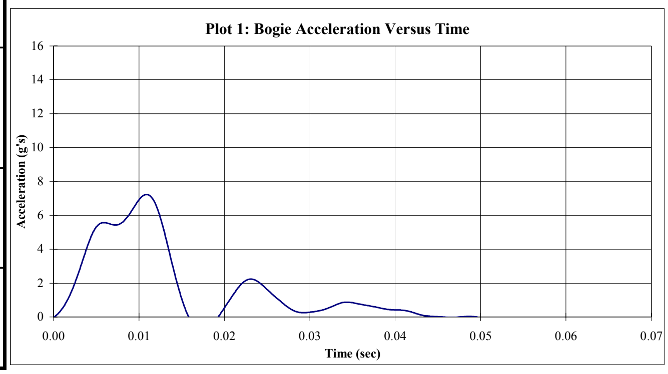
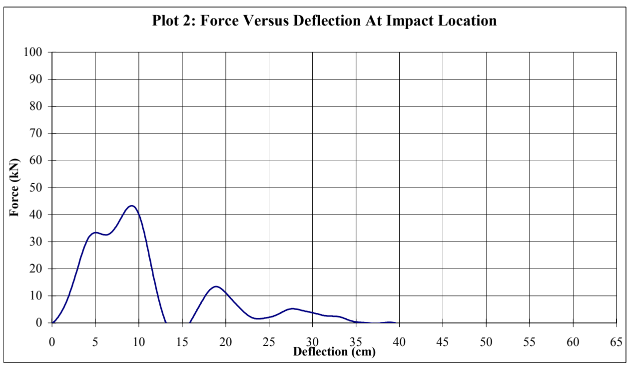


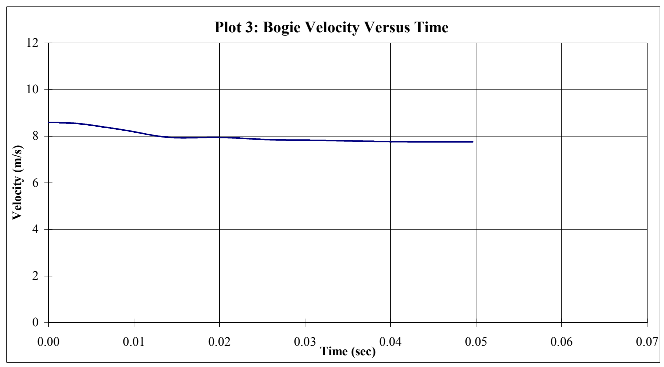
Figure 29. Results of WP-21

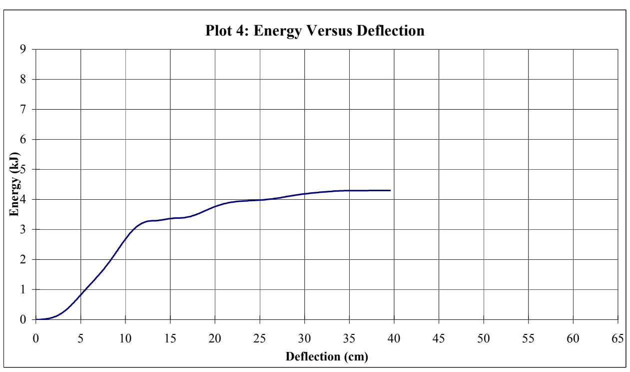
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-22		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line is low on impact face, but high on opposite face, ring lines are not very apparent, short jagged splinters		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.6 m/s	(19.2 mph)	(28.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









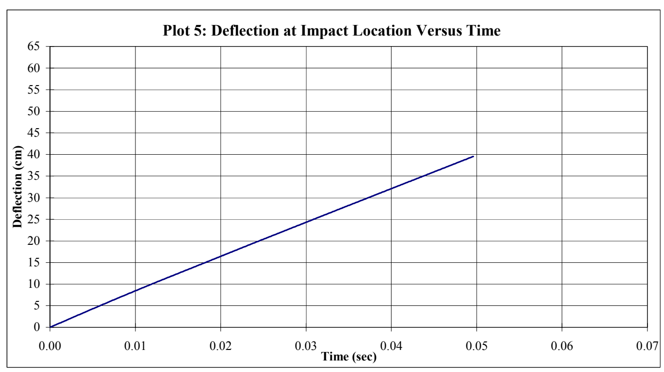
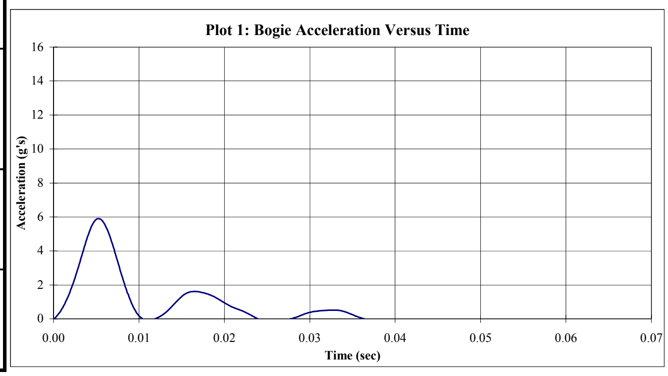


Figure 30. Results of WP-22

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-23		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line is approximately level with ground, break line is very jagged with short rough splinters		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.5 m/s	(21.3 mph)	(31.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		



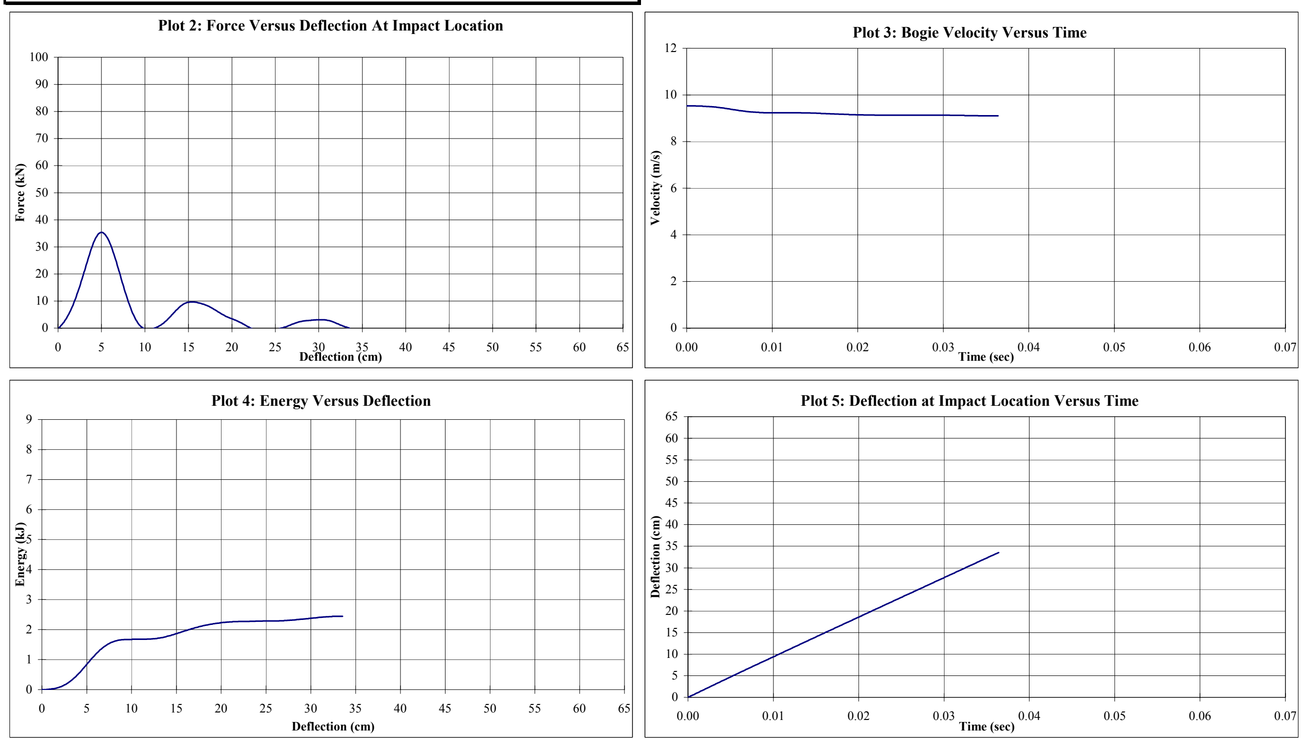
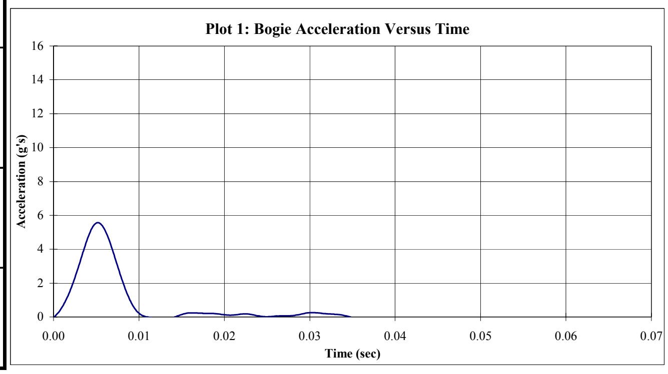
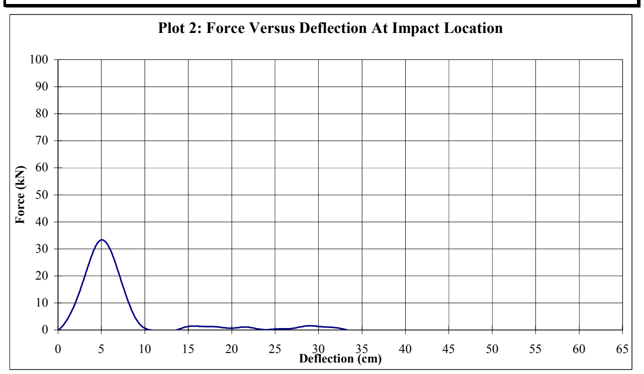


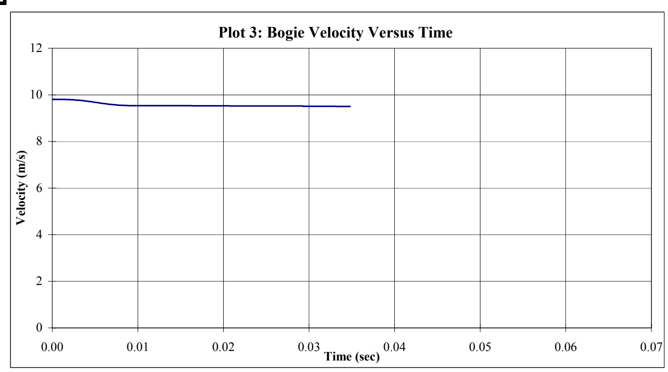
Figure 31. Results of WP-23

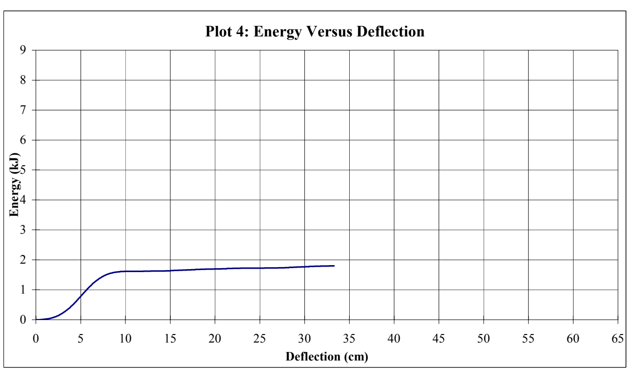
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-24		
Test Date:	27-Jun-2003		
Failure Type:	Fracture is one large peak with splinters on both sides, peak surrounds a major knot, break is approximately at ground level		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	9.8 m/s	(21.9 mph)	(32.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









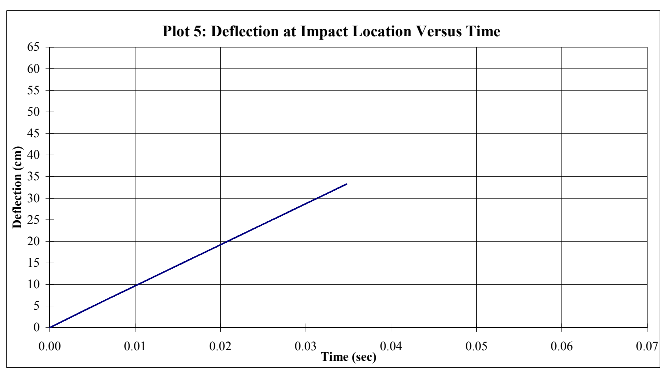
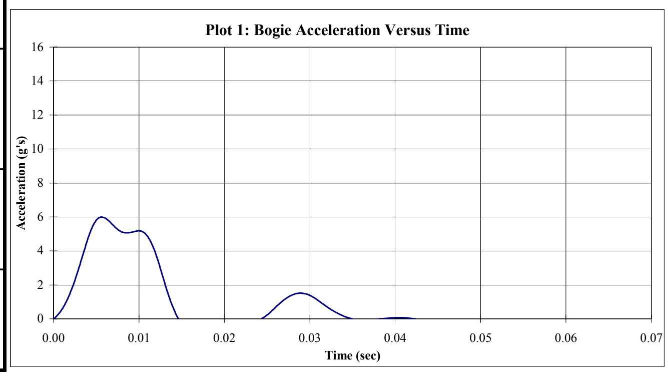
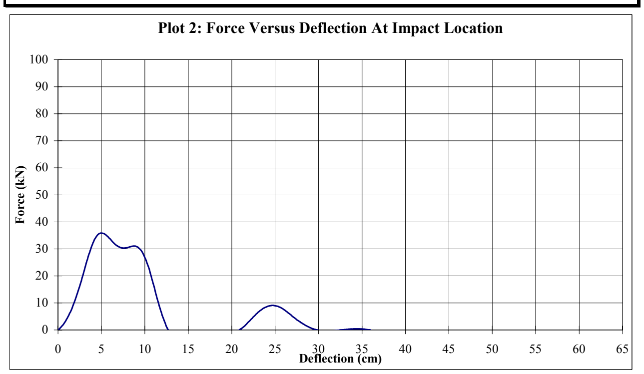


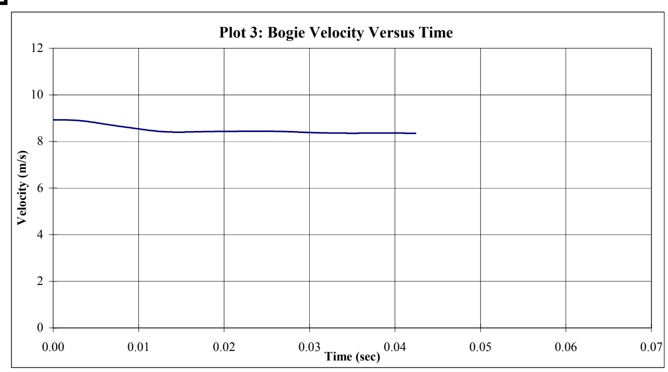
Figure 32. Results of WP-24

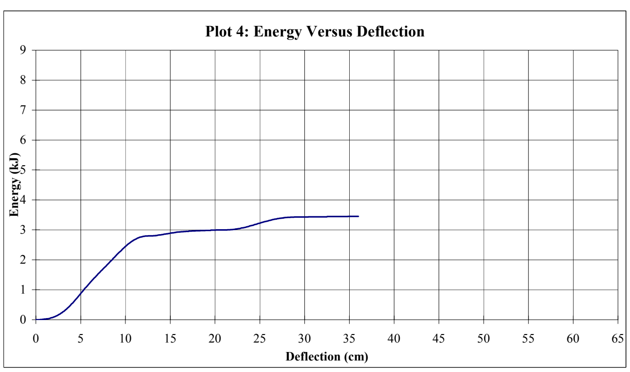
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees			
Test Number:	WISC WP-25			
Test Date:	27-Jun-2003			
Failure Type:	Very jagged fracture line with two distinct peaks, splinters along slopes of peaks, fracture just below ground line			
Post Properties				
Post Type:	sconsin White Pine			
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"	
Post Length:	182.9	cm	(72.0 in)	
Embedment Depth:	96.5	cm	(38.0 in)	
Soil Properties				
Gradation:	Steel Sleeve			
Moisture Content:	NA			
Compaction Method:	NA			
Soil Density, γ_d:	NA	kg/m³	#VALUE!	
Bogie Properties				
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)	
Impact Location:	55.0 cm	(21.7 in)	above groundline	
Bogie Mass:	611 kg	(1346 lbf)		
Data Acquired				
Accelerometer Data:	EDR-4			
Camera Data:	Side View-Digital			









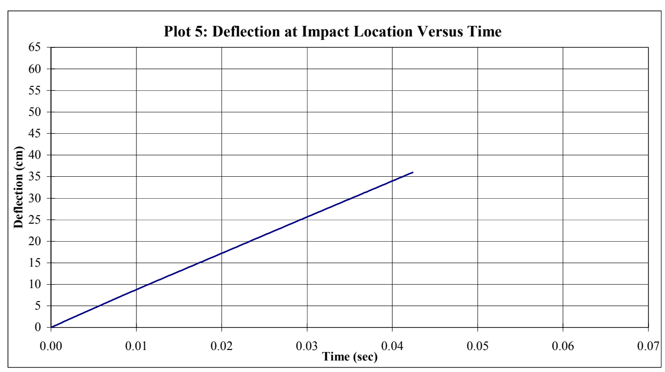
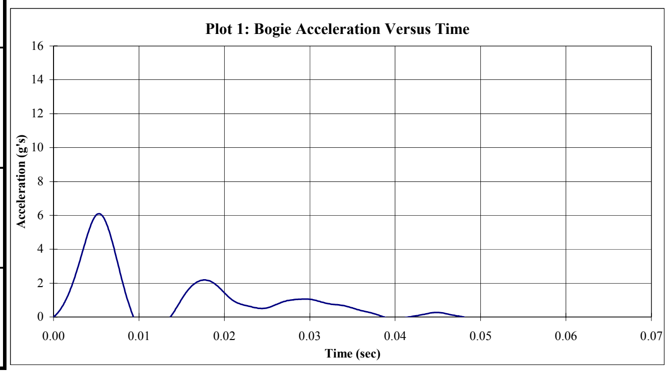
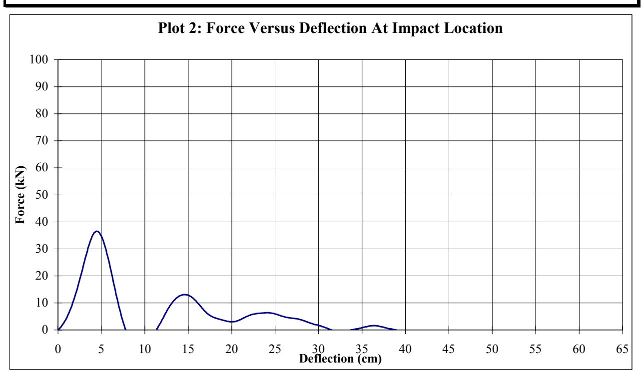


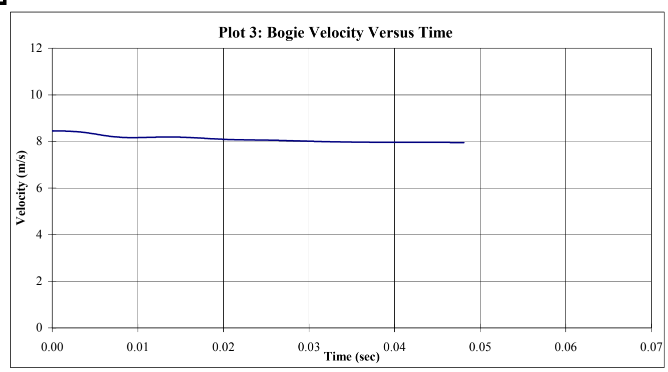
Figure 33. Results of WP-25

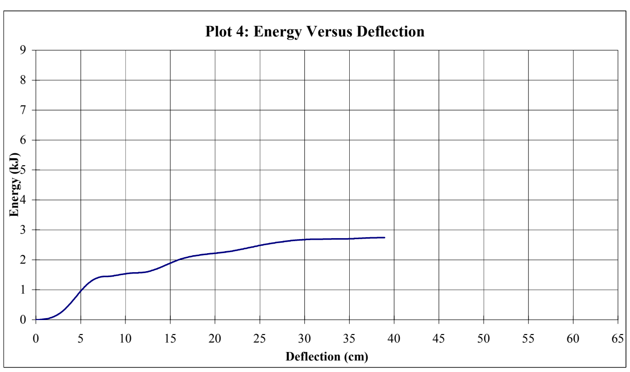
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-26		
Test Date:	27-Jun-2003		
Failure Type:	Two distinct levels of fracture line, impact face below ground, opposite face at or above ground level, very jagged break line		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.4 m/s	(18.9 mph)	(27.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









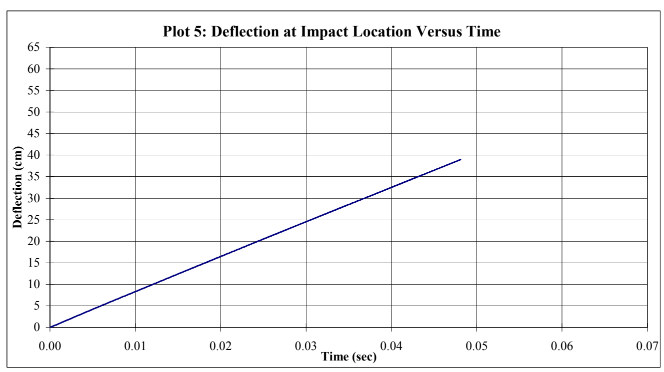
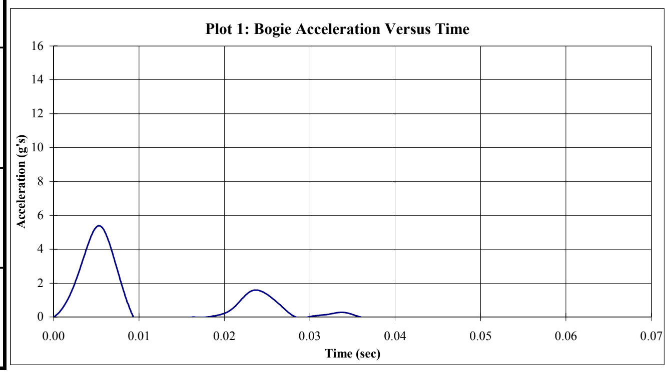
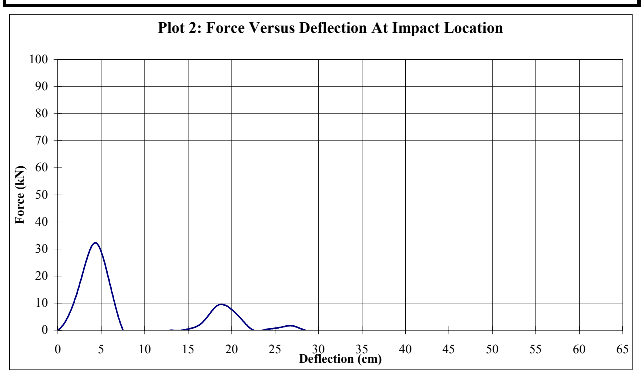


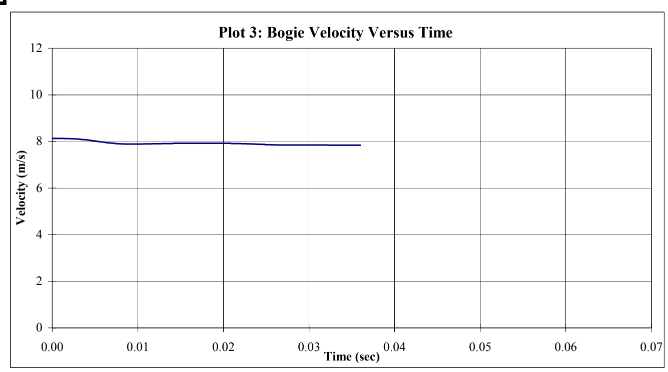
Figure 34. Results of WP-26

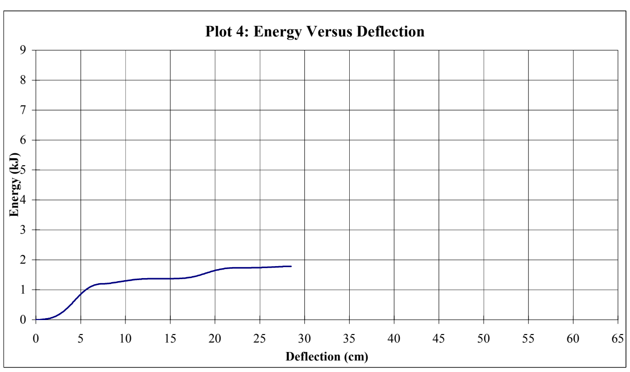
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-27		
Test Date:	27-Jun-2003		
Failure Type:	Fracture line entirely below ground level with random peaks, short rough splinters		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.1 m/s	(18.2 mph)	(26.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









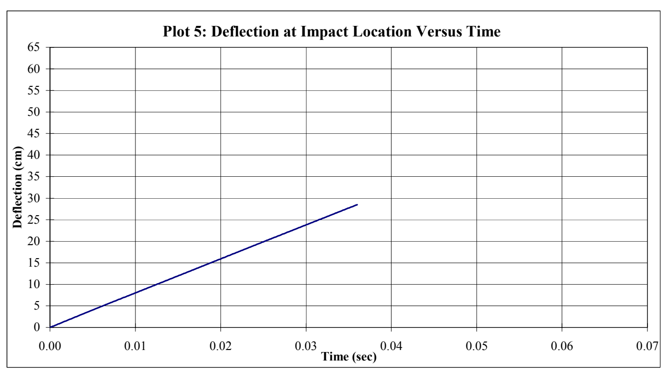
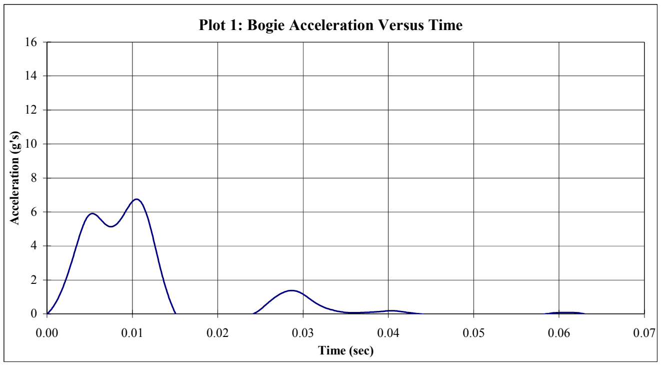
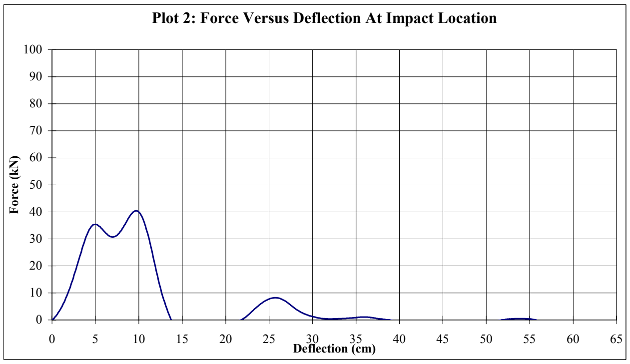


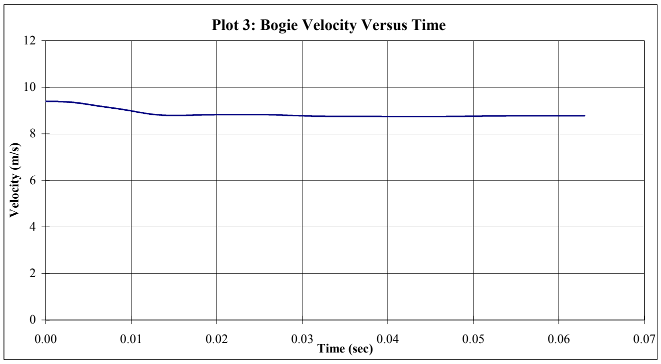
Figure 35. Results of WP-27

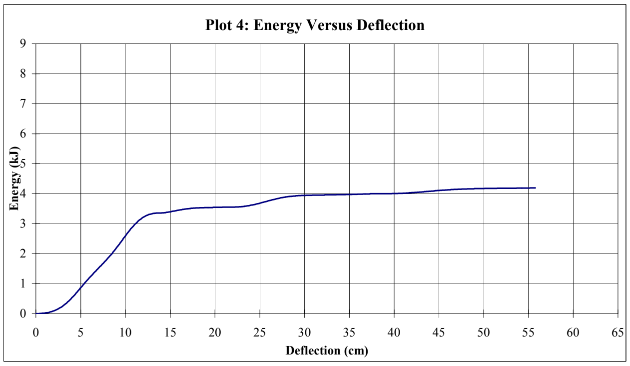
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-28		
Test Date:	27-Jun-2003		
Failure Type:	Very jagged fracture line, peak on right impact corner, lowest part of break is at ground level		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	9.4 m/s	(21.0 mph)	(30.8 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









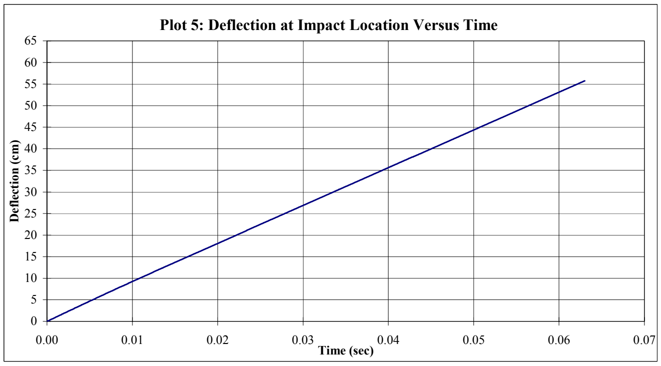
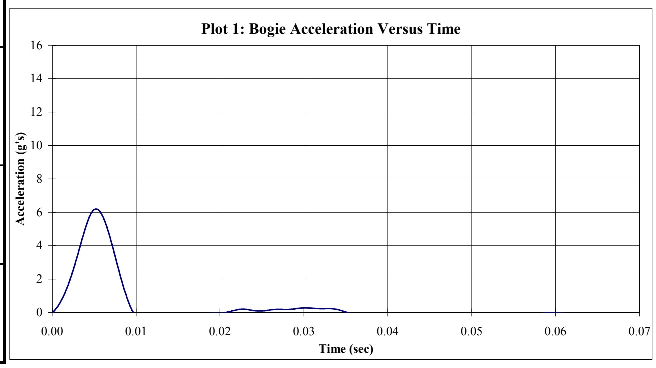
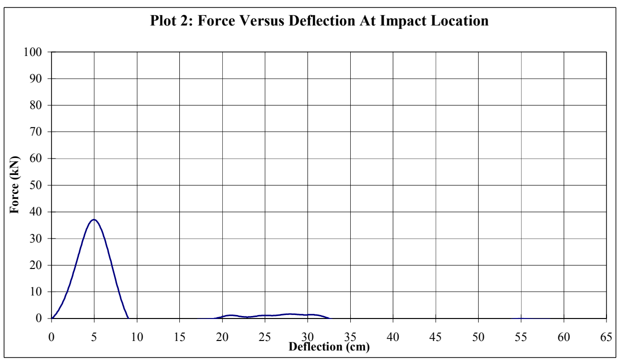


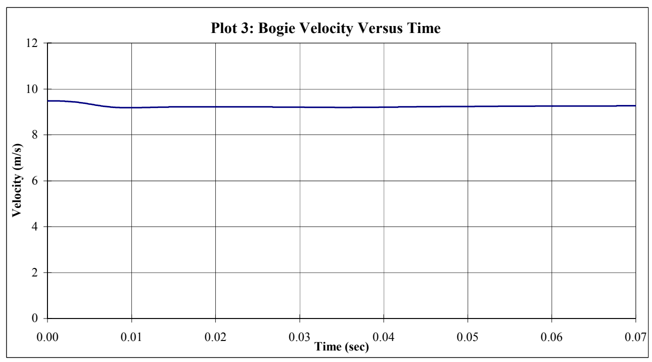
Figure 36. Results of WP-28

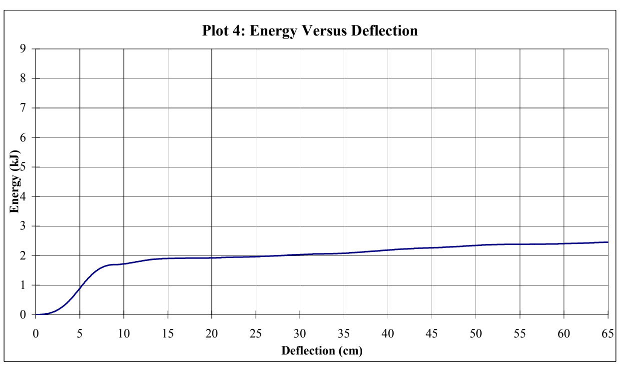
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-29		
Test Date:	27-Jun-2003		
Failure Type:	Jagged break with extremely long peaks, break is above ground entirely		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	9.5 m/s	(21.2 mph)	(31.1 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









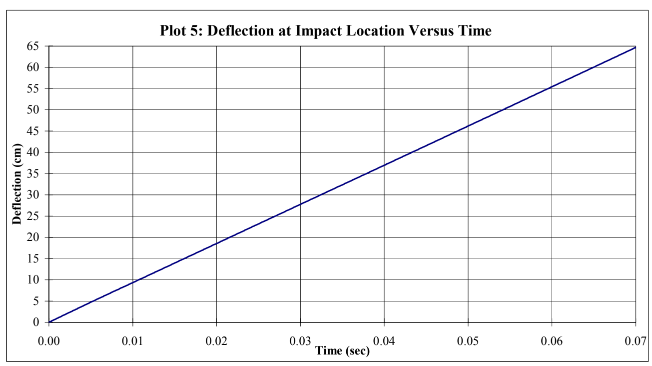
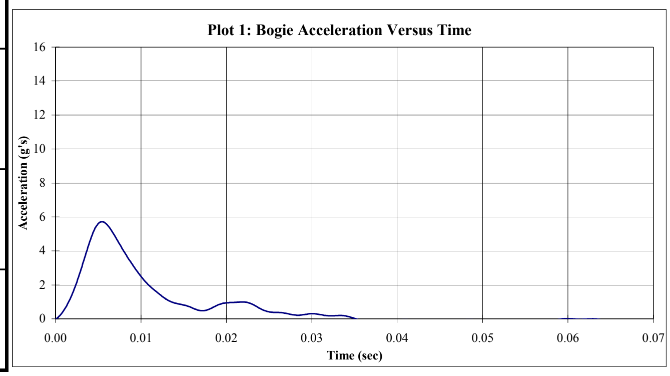


Figure 37. Results of WP-29

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC WP-30		
Test Date:	27-Jun-2003		
Failure Type:	Flat fracture line beneath groung level, very rough short splinters, ring lines not extremely apparent		
Post Properties			
Post Type:	sconsin White Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		



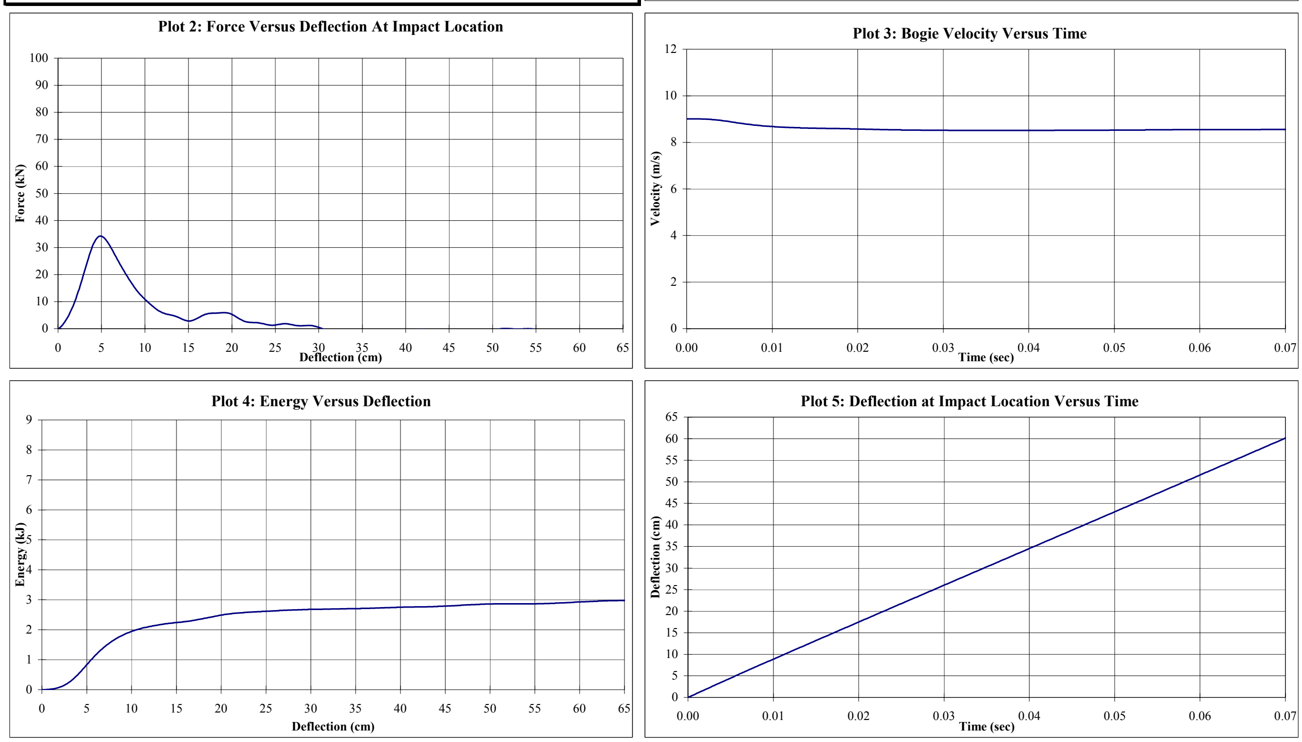
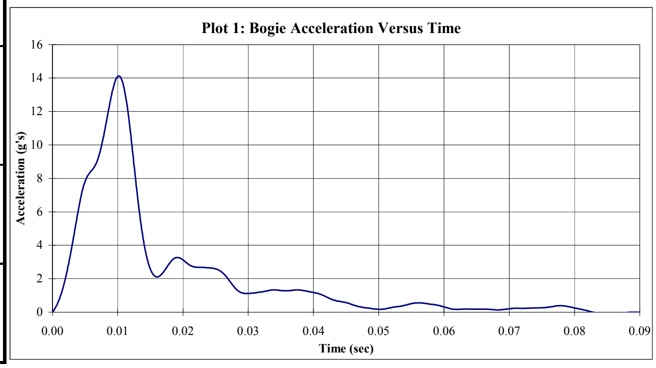
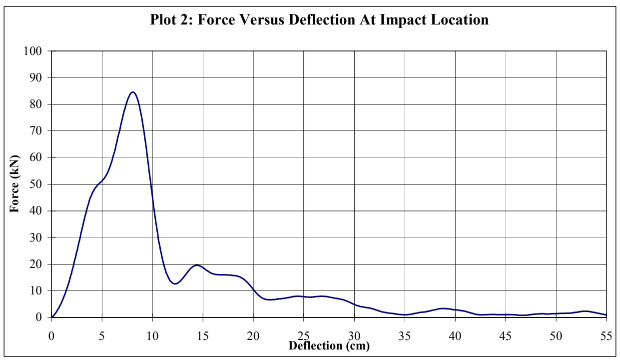


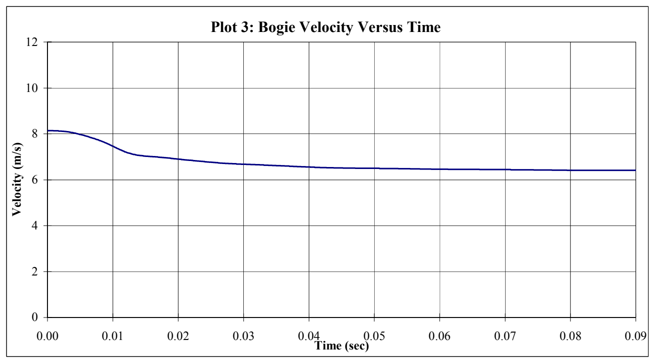
Figure 38. Results of WP-30

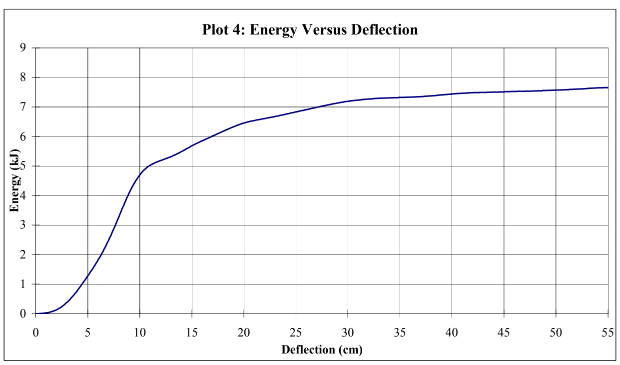
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-1		
Test Date:	26-Jun-2003		
Failure Type:	Long splintering at break-line, bottom and top still attached		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.1 m/s	(18.2 mph)	(26.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









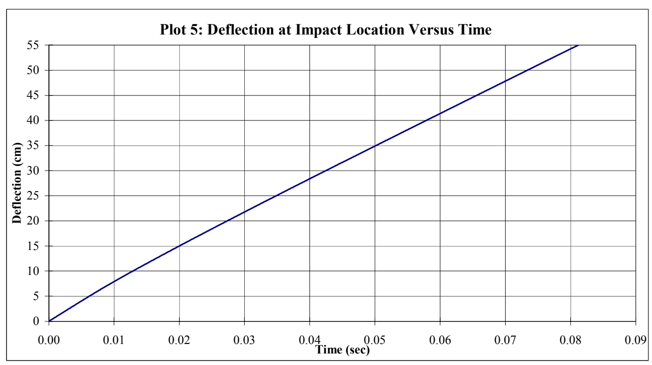


Figure 39. Results of RP-1

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-2		
Test Date:	26-Jun-2003		
Failure Type:	Fractured slightly below top of sleeve, long splinters, fractured along ring lines		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric		6" x 8"
Post Length:	182.9 cm		(72.0 in)
Embedment Depth:	96.5 cm		(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³		#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		

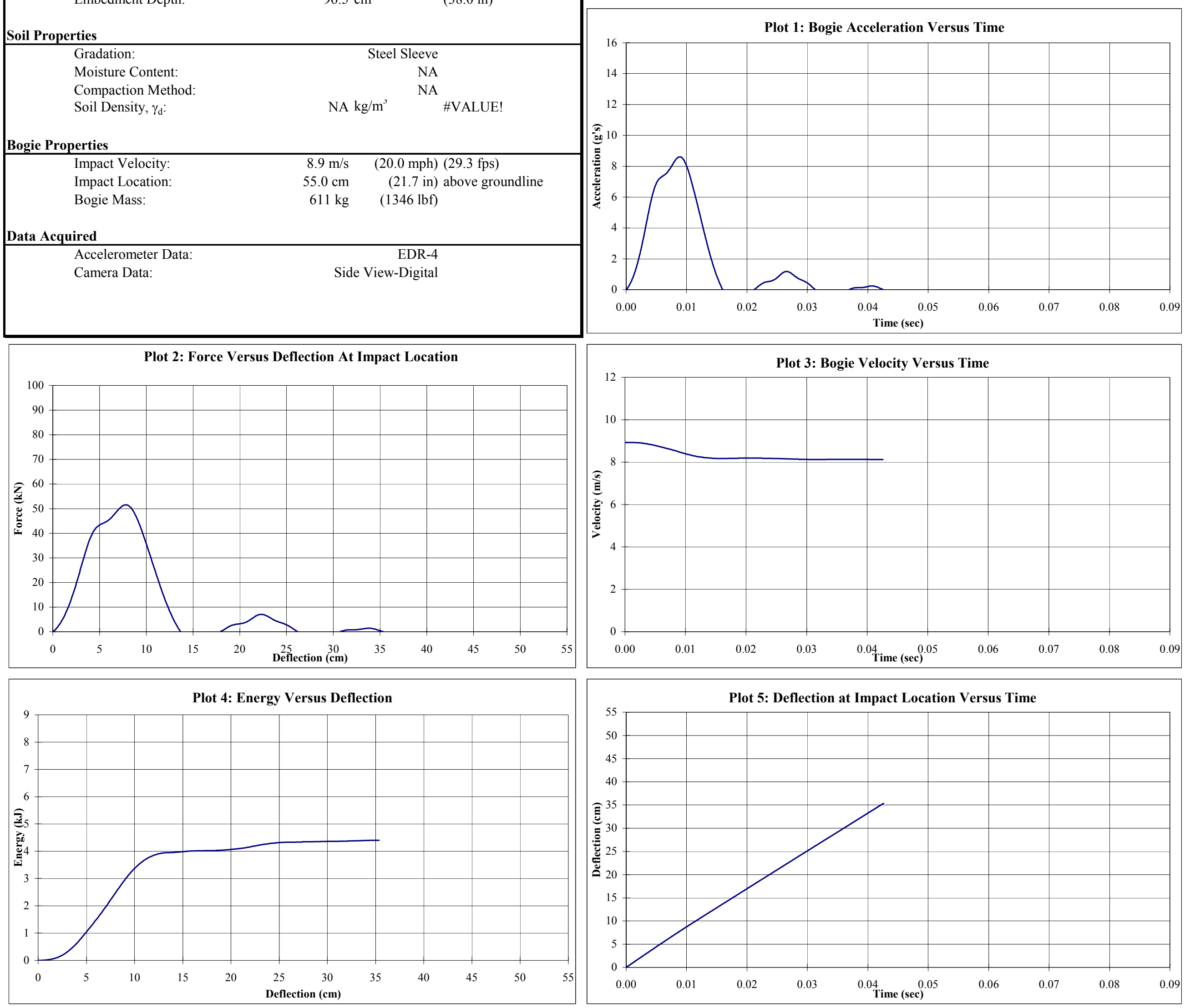
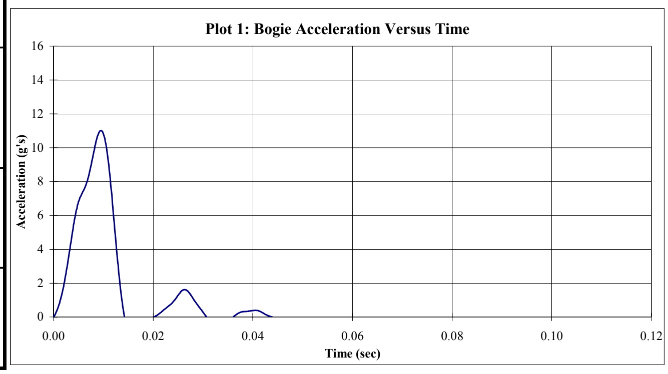
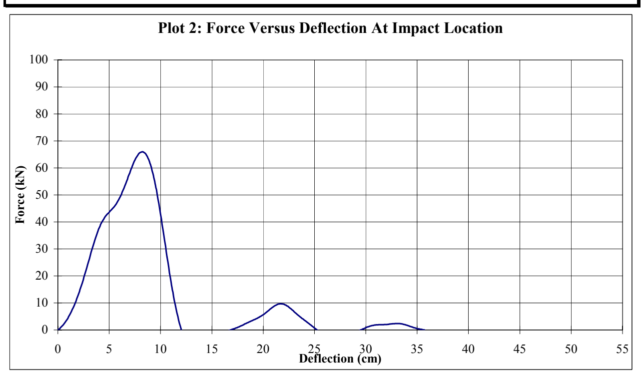


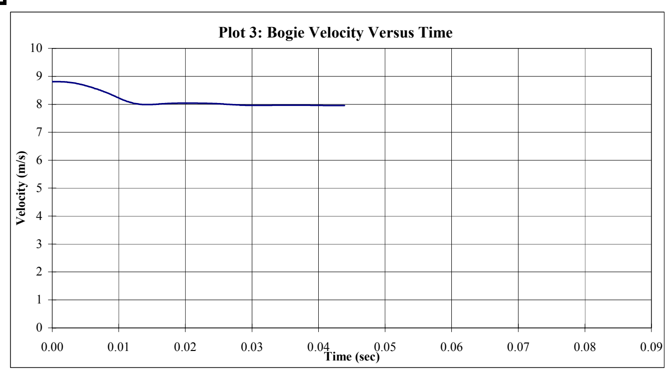
Figure 40. Results of RP-2

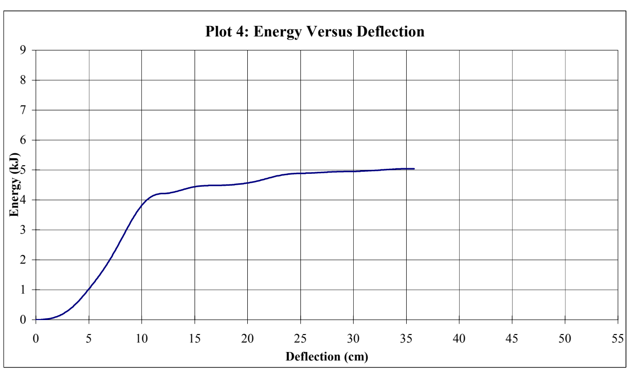
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-3		
Test Date:	26-Jun-2003		
Failure Type:			
	0		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(28.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









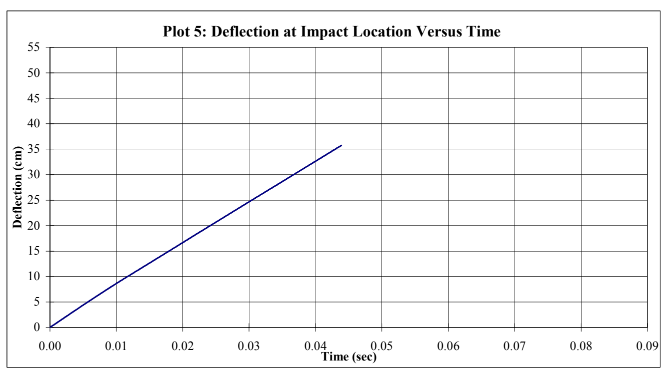
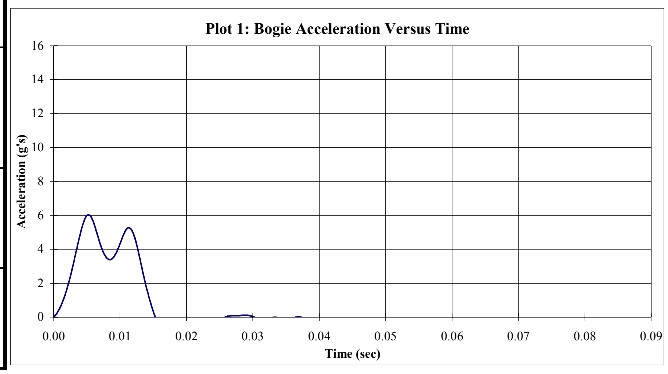
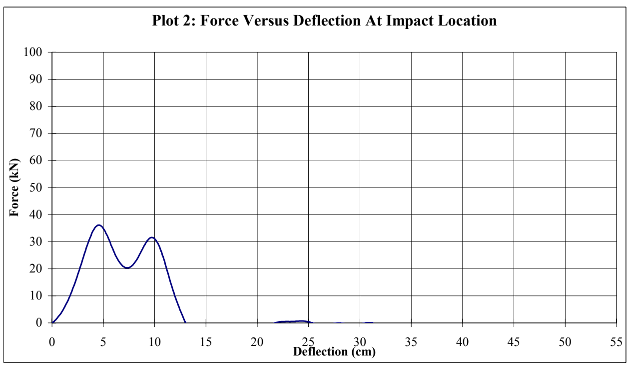


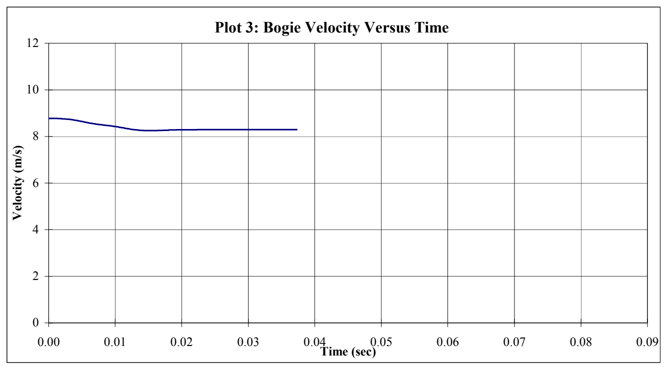
Figure 41. Results of RP-3

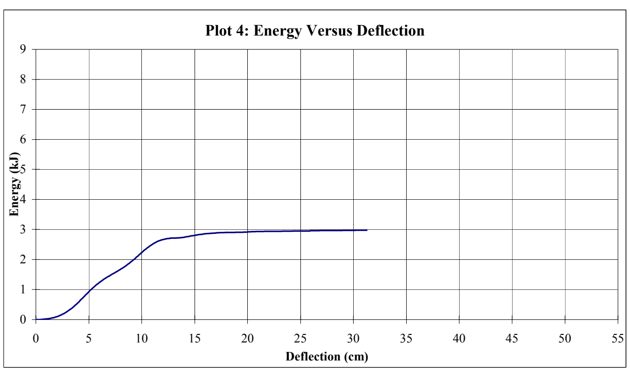
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-4		
Test Date:	26-Jun-2003		
Failure Type:	Less splintering than previously noticed, ring lines are not as apparent in the break		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.6 mph)	(28.8 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









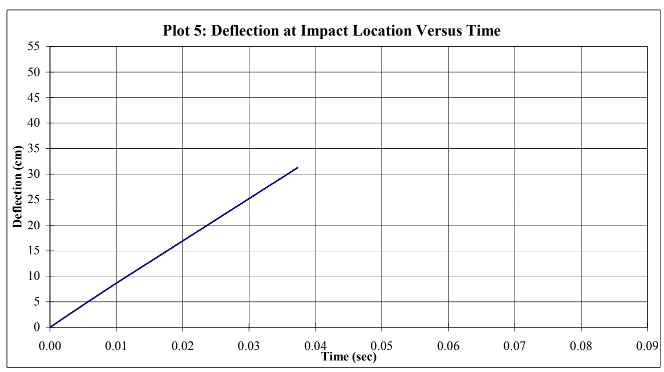
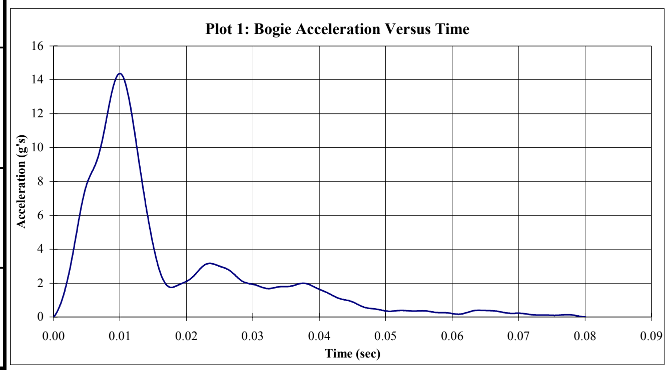


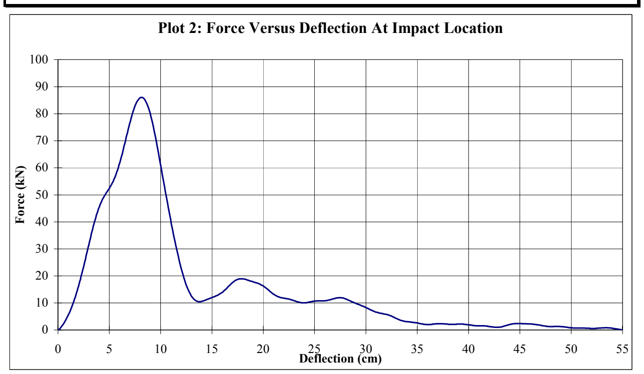
Figure 42. Results of RP-4

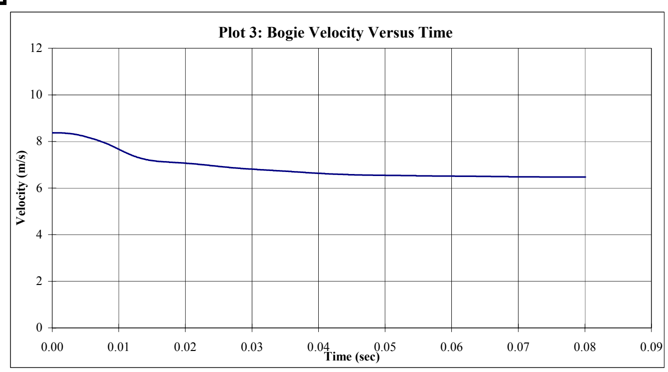
Midwest Roadside Safety Facility

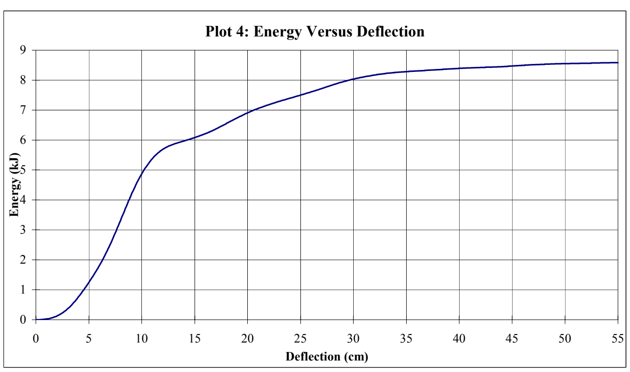
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-5		
Test Date:	26-Jun-2003		
Failure Type:	Short splintering, again with ring pattern noticed in the break line		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.4 m/s	(18.7 mph)	(27.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









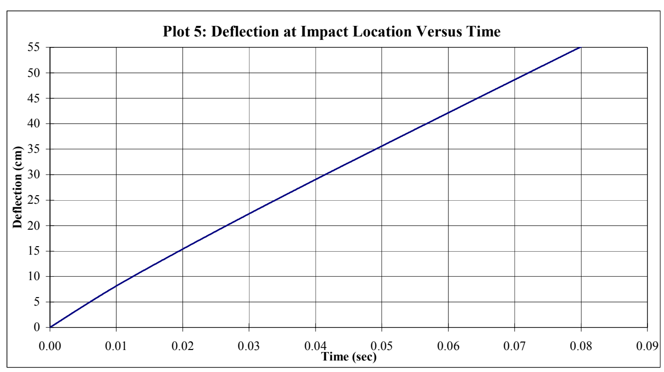
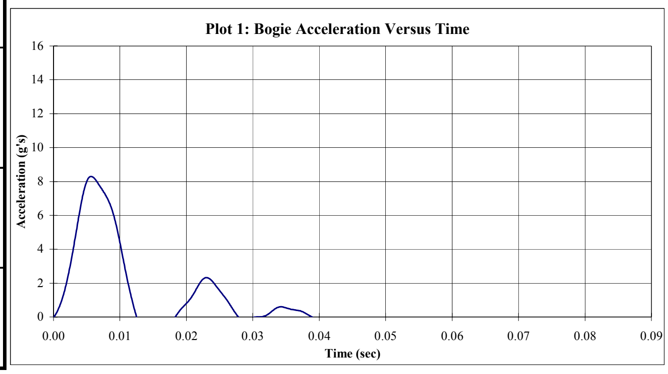
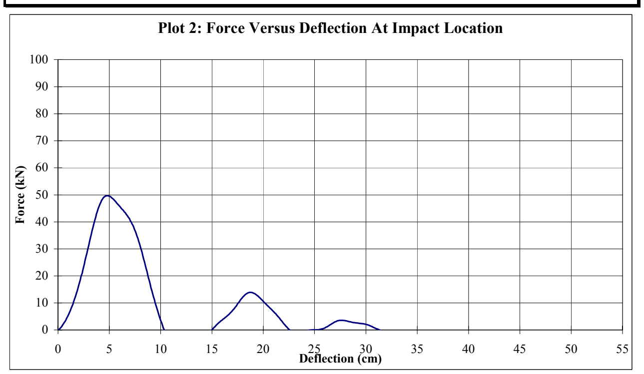
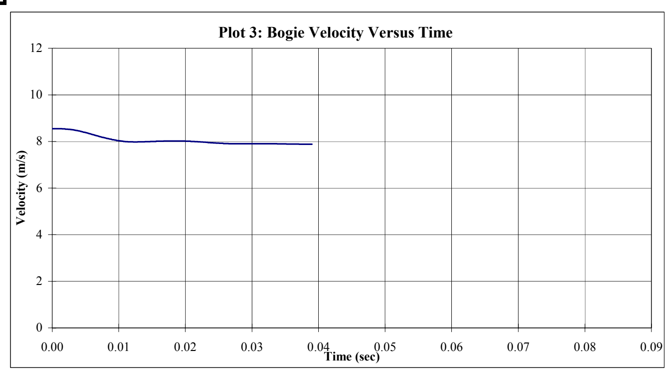


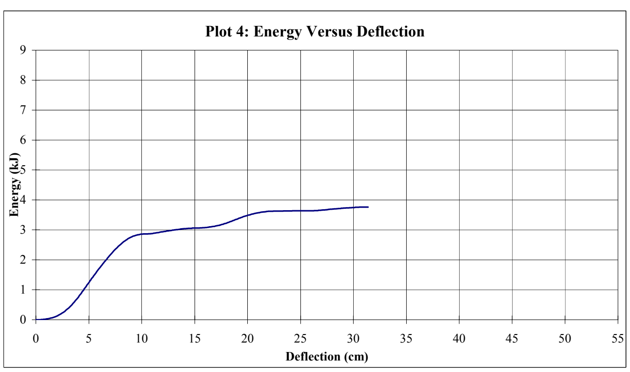
Figure 43. Results of RP-5

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-6		
Test Date:	26-Jun-2003		
Failure Type:	Less splintering, those splinters that do exist are short, ring pattern is again less noticeable than it is in most other posts		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.5 m/s	(19.1 mph)	(28.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









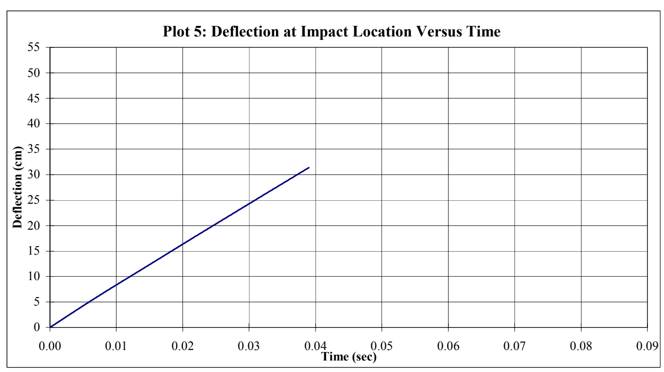
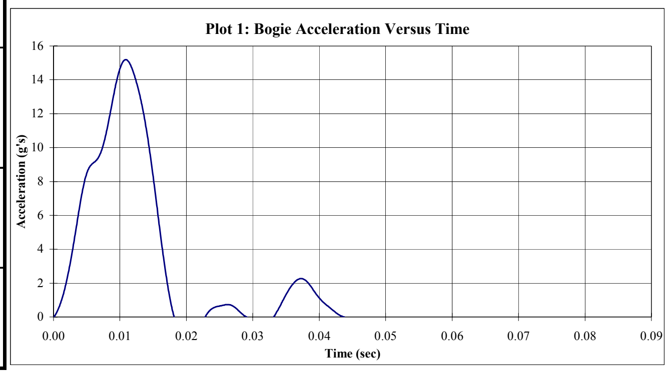
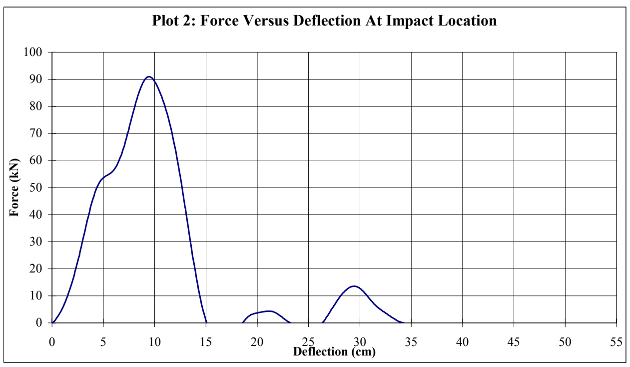


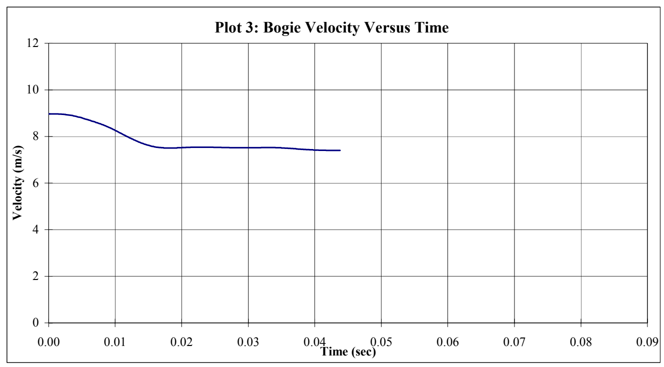
Figure 44. Results of RP-6

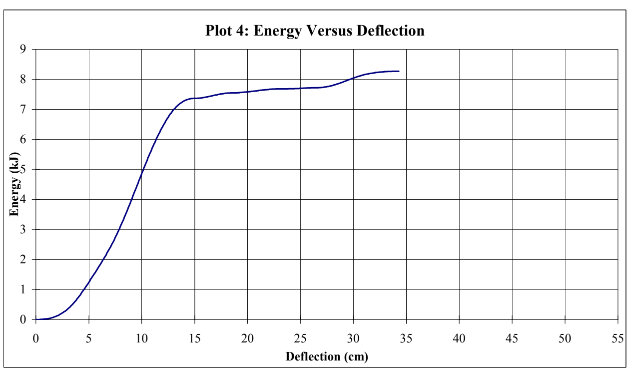
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-7		
Test Date:	26-Jun-2003		
Failure Type:	Very long splinters, post did not break completely from base		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric		6" x 8"
Post Length:		182.9 cm	(72.0 in)
Embedment Depth:		96.5 cm	(38.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:		NA kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.1 mph)	(29.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









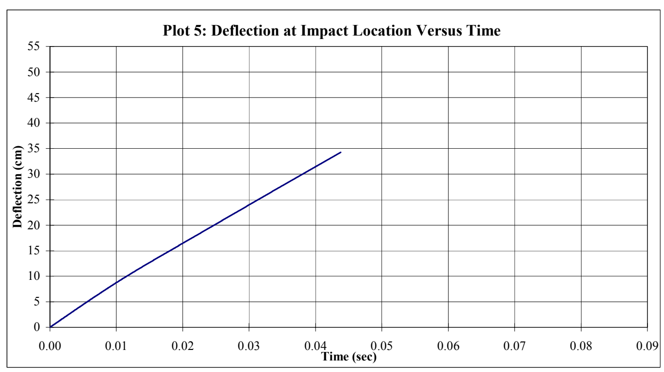
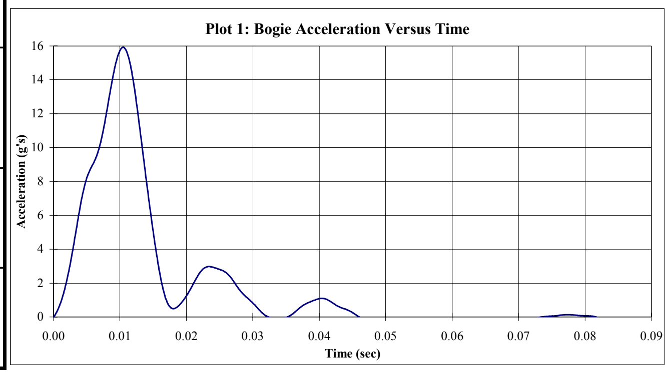
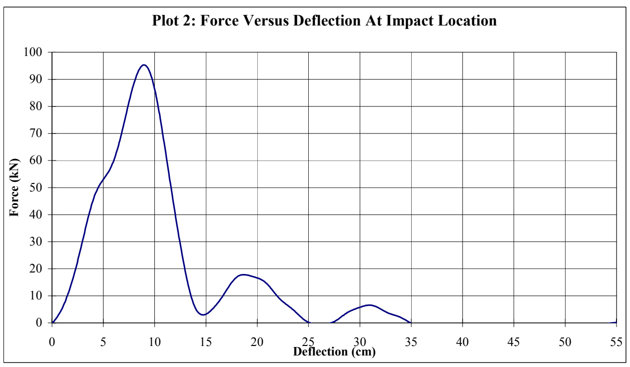
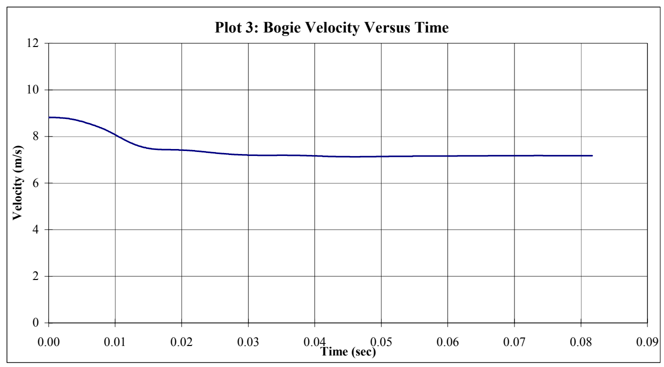


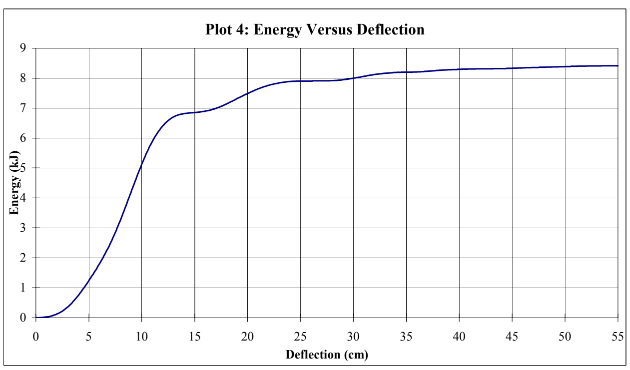
Figure 45. Results of RP-7

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-8		
Test Date:	26-Jun-2003		
Failure Type:	Very similar to post RP7, long splinters, very jagged, post did not fully separate at fracture line		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(28.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









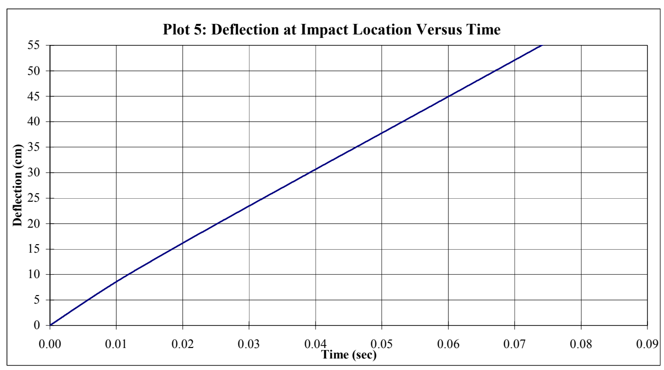
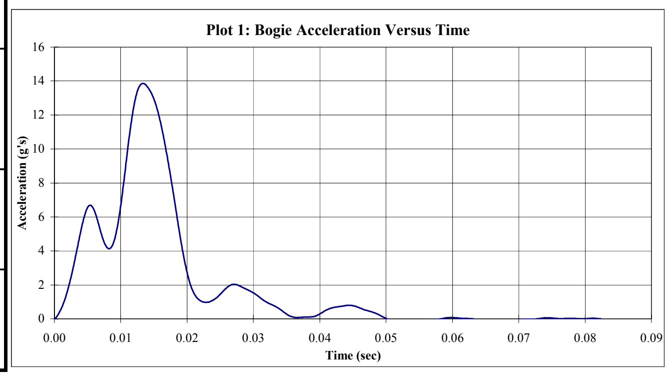
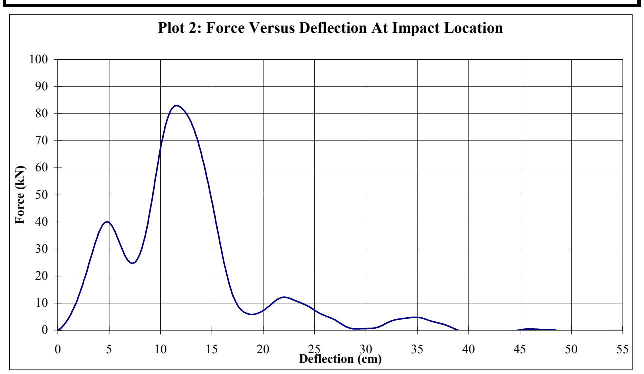
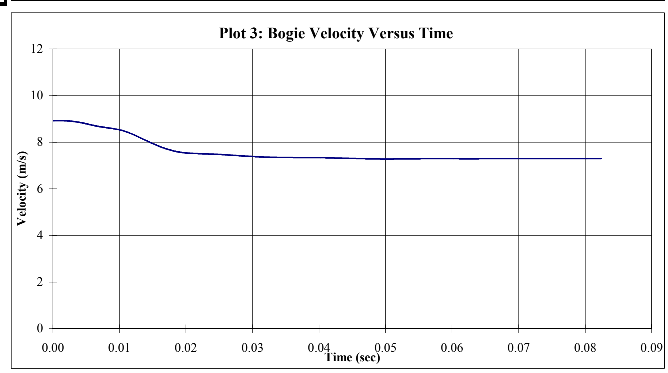


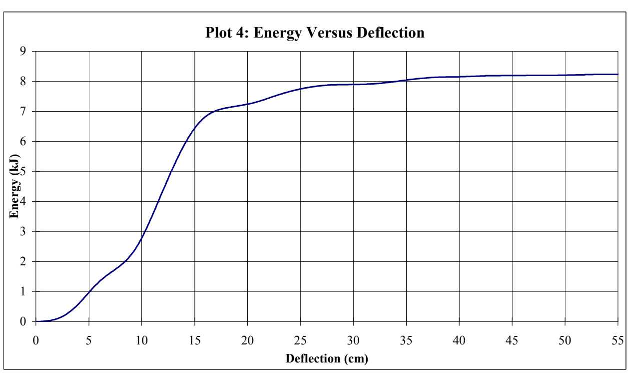
Figure 46. Results of RP-8

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-9		
Test Date:	26-Jun-2003		
Failure Type:	Similar to RP 7 & 8, but less jagged, post did not separate at fracture line.		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









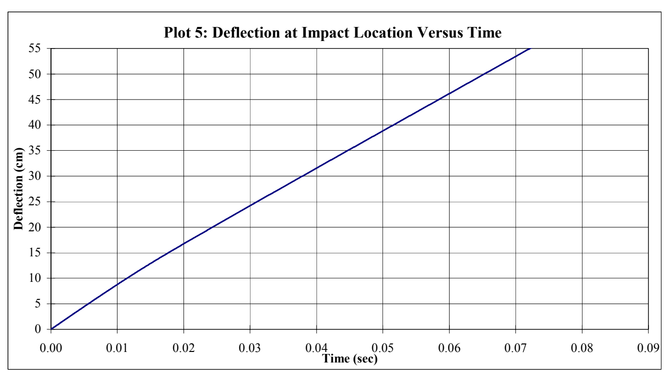
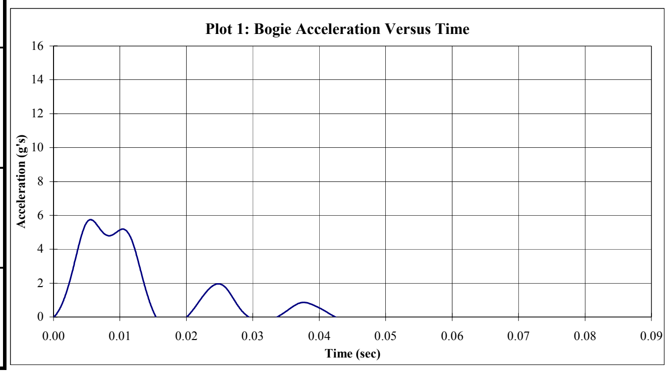
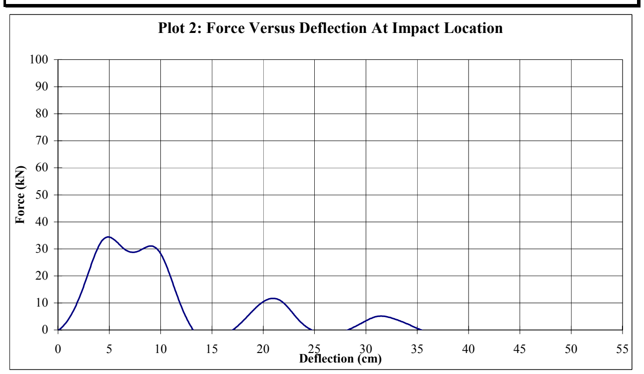


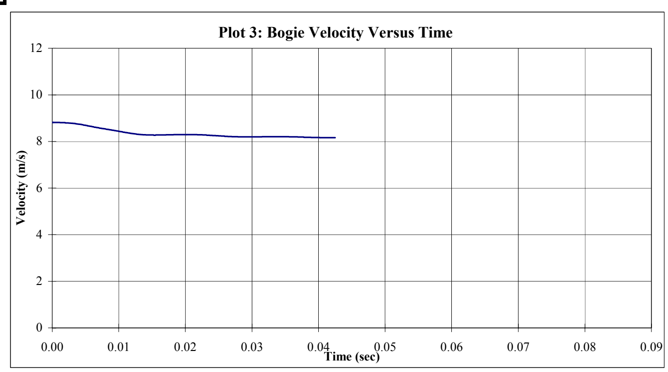
Figure 47. Results of RP-9

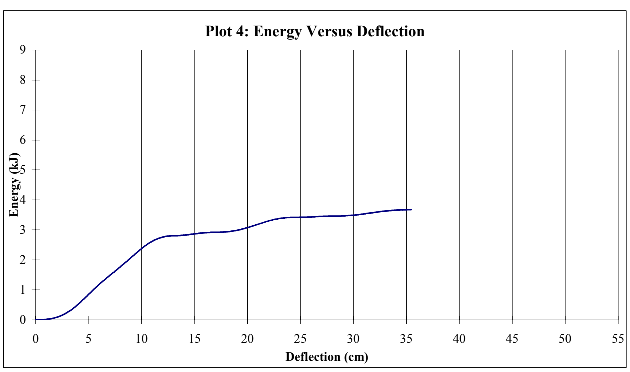
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-10		
Test Date:	26-Jun-2003		
Failure Type:	Ring pattern is noticeable in fracture line, splinters are short		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(28.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









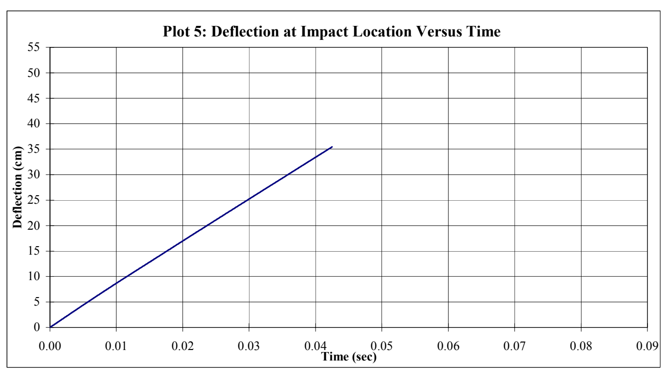
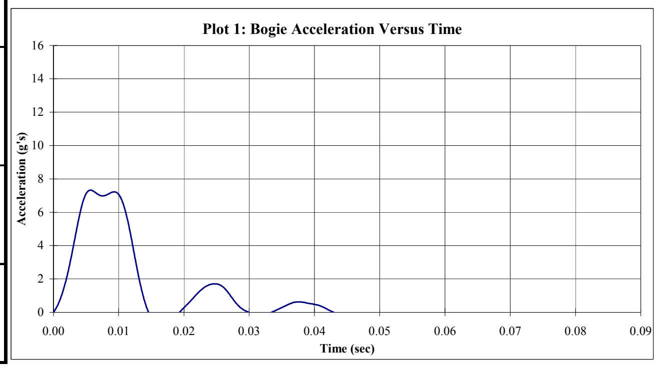
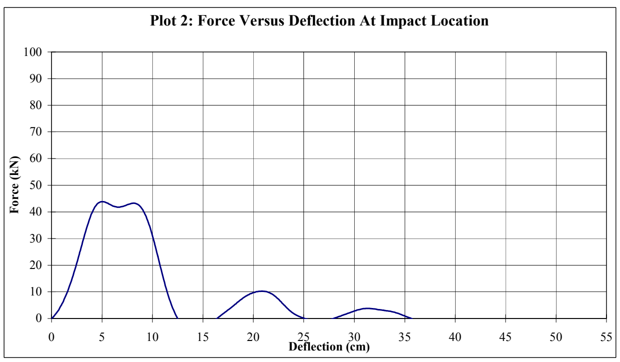


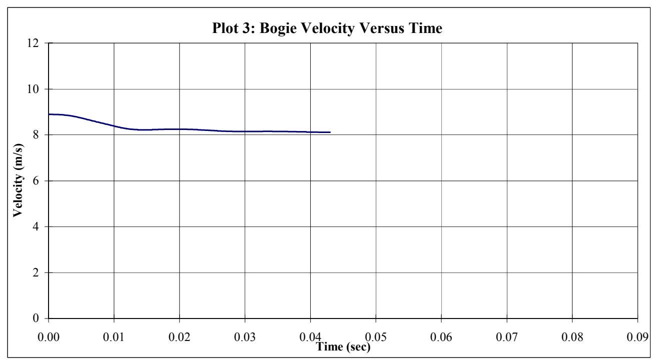
Figure 48. Results of RP-10

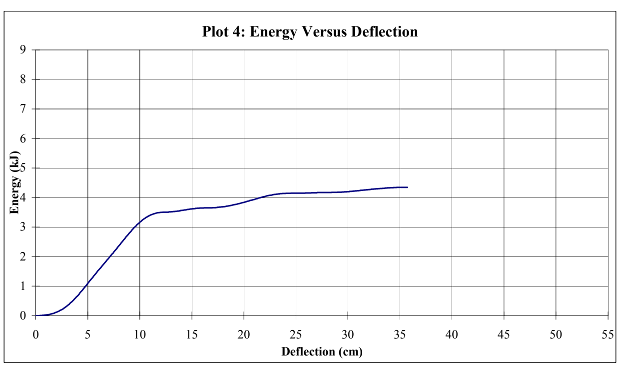
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-11		
Test Date:	26-Jun-2003		
Failure Type:	Similar to RP10, ring pattern is noticeable, splinters are short		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.9 mph)	(29.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









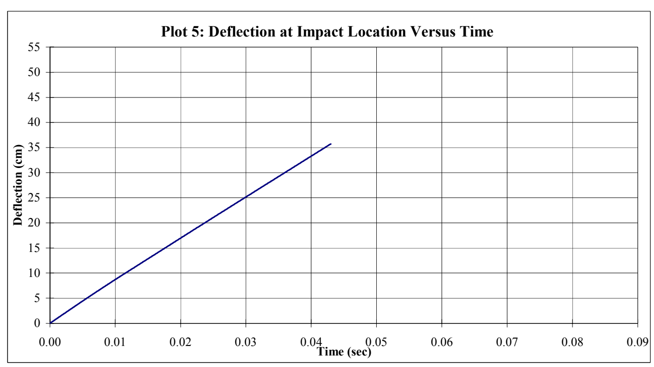
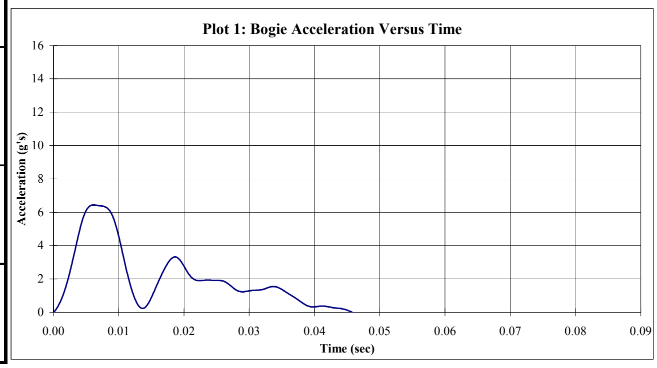
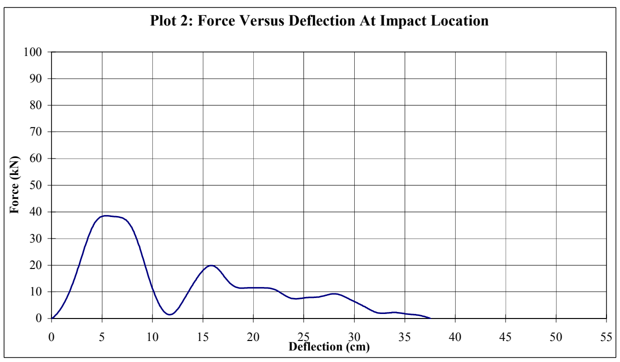


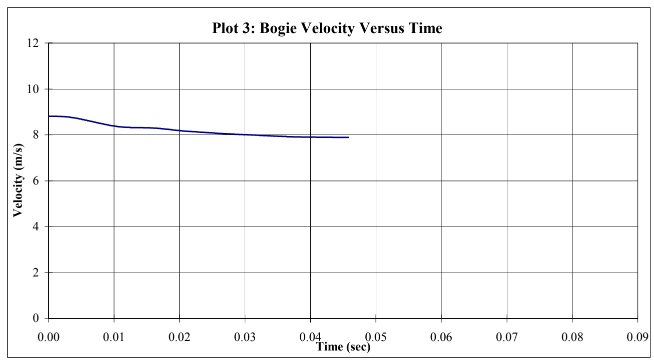
Figure 49. Results of RP-11

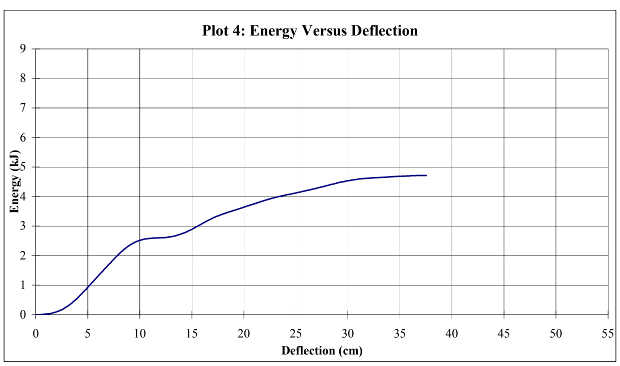
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-12		
Test Date:	26-Jun-2003		
Failure Type:	Post fractured below ground surface, has moderately jagged fracture line, ring pattern slightly noticeable in fracture line		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(28.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









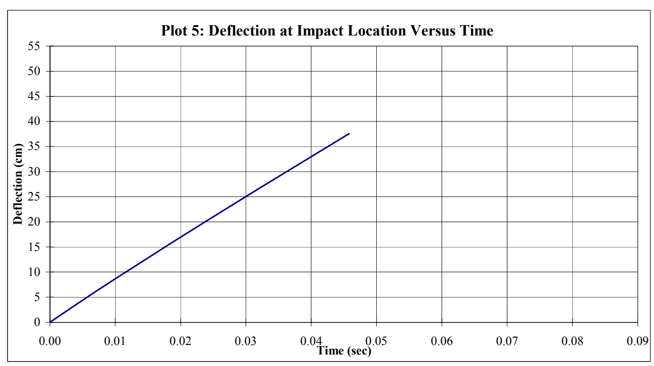
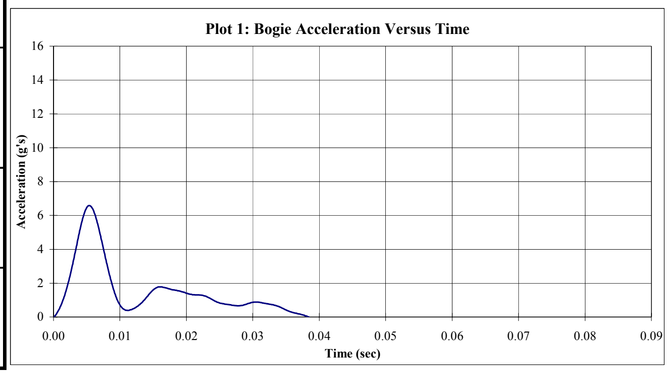
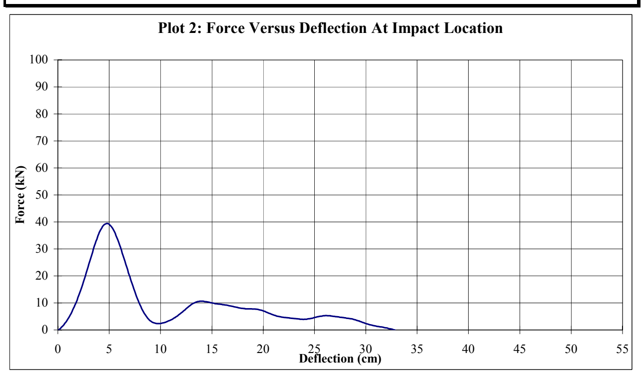
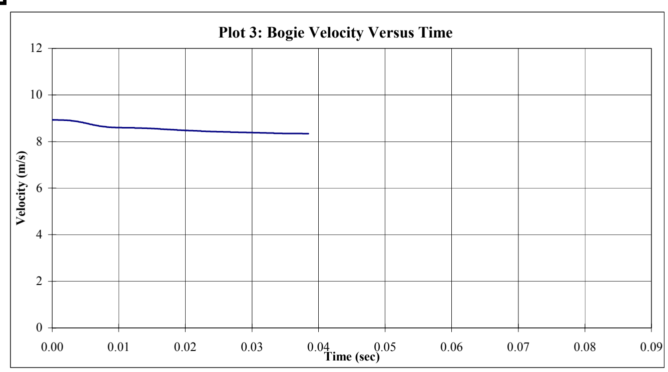


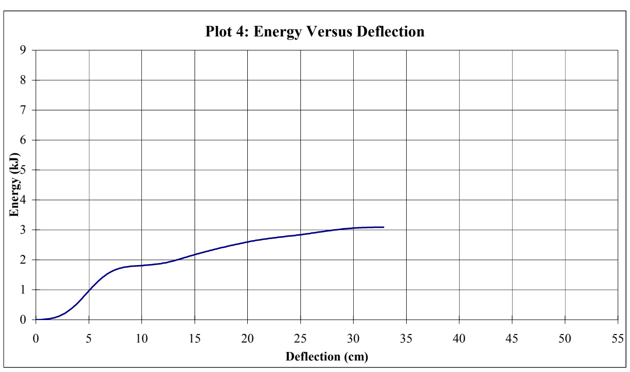
Figure 50. Results of RP-12

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-13		
Test Date:	26-Jun-2003		
Failure Type:	Fracture line approx. 2" below ground surface, short splinters		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









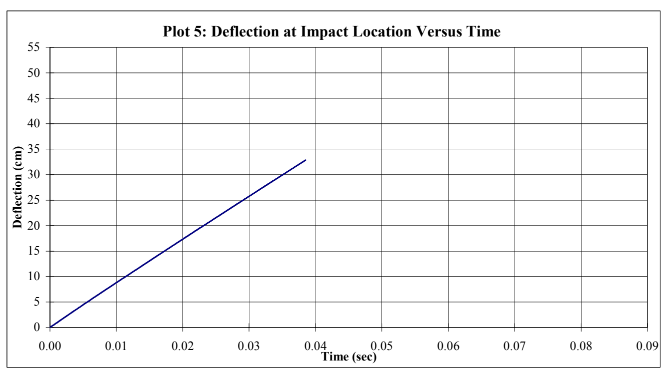
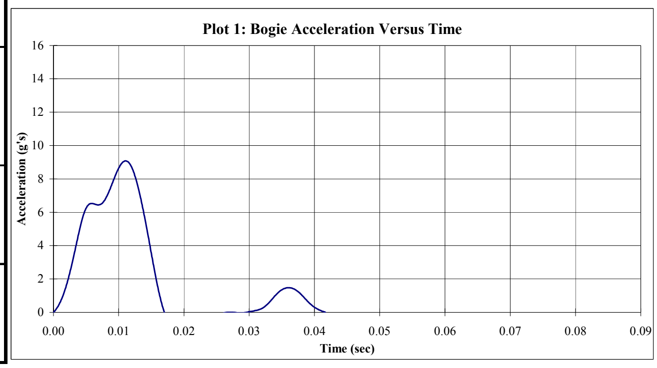
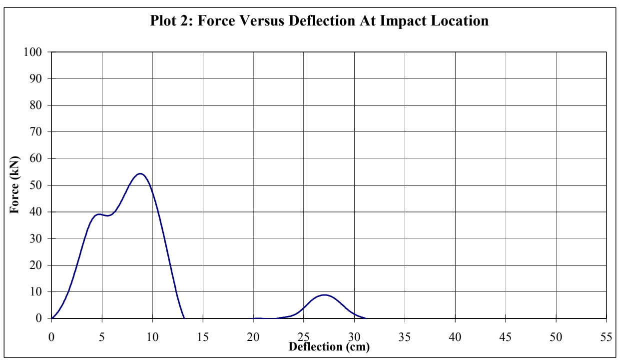


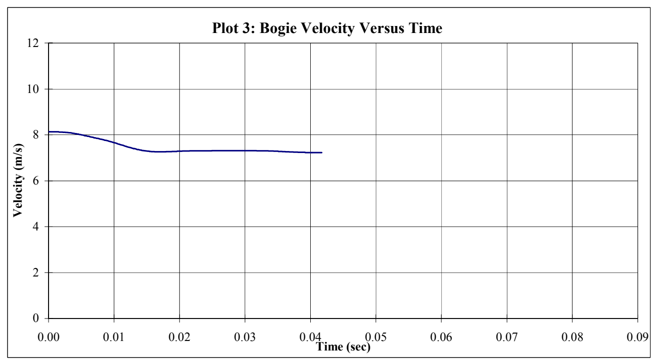
Figure 51. Results of RP-13

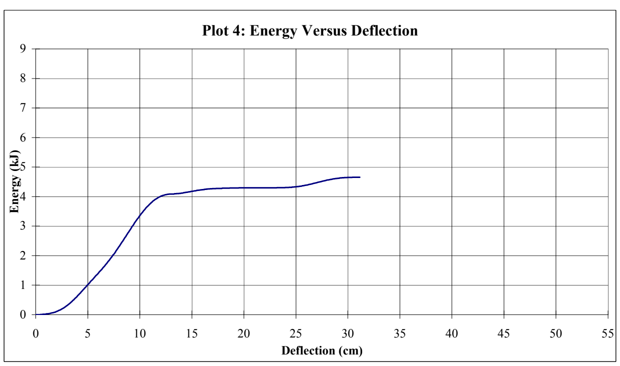
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-14		
Test Date:	26-Jun-2003		
Failure Type:	Fractured below ground surface, ring marks noticeable in fracture line, moderately jagged end.		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.1 m/s	(18.2 mph)	(26.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









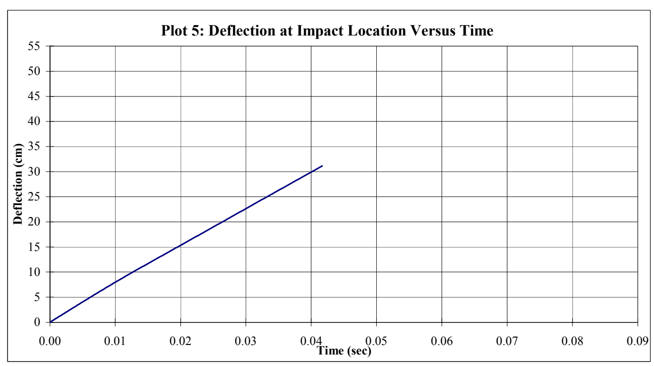
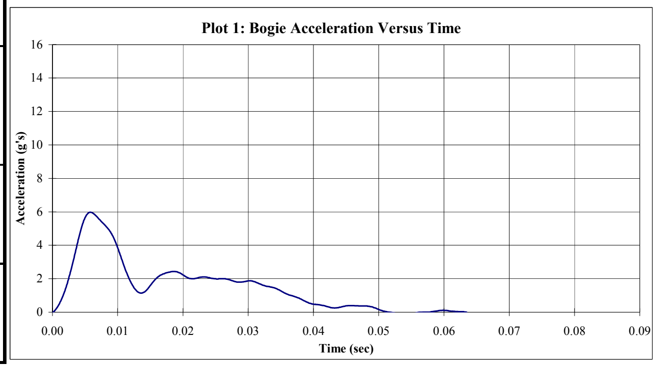
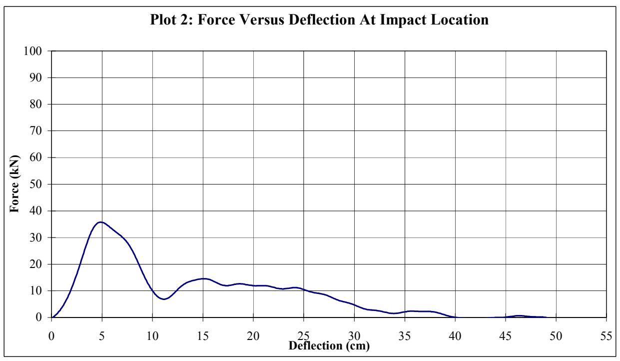
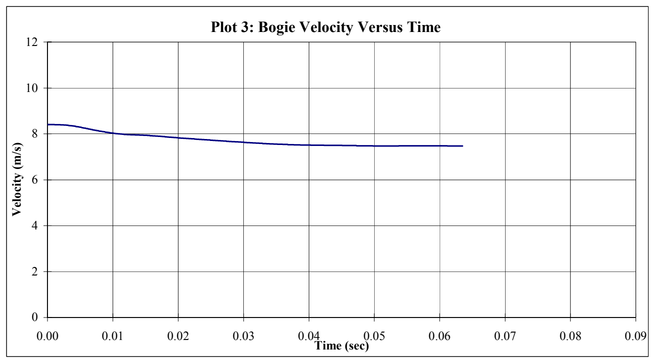


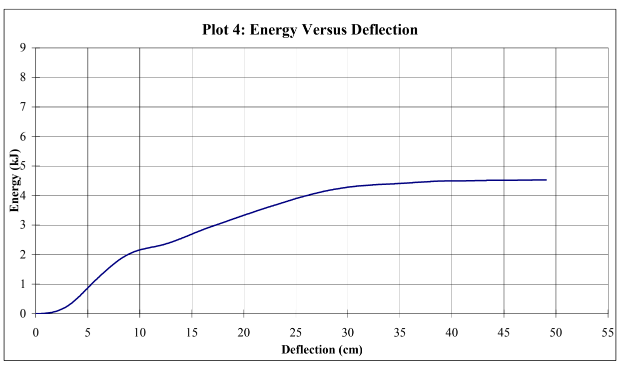
Figure 52. Results of RP-14

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-15		
Test Date:	26-Jun-2003		
Failure Type:	Fractured below ground surface, ring marks only slightly noticeable in fracture line, moderately jagged end.		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric		6" x 8"
Post Length:	182.9 cm		(72.0 in)
Embedment Depth:	96.5 cm		(38.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		#VALUE!
Bogie Properties			
Impact Velocity:	8.4 m/s	(18.8 mph)	(27.6 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









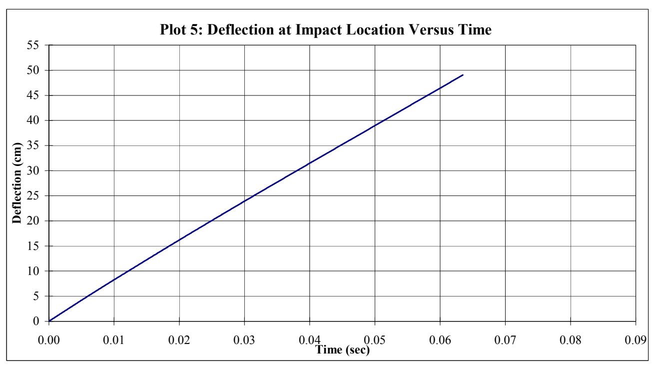
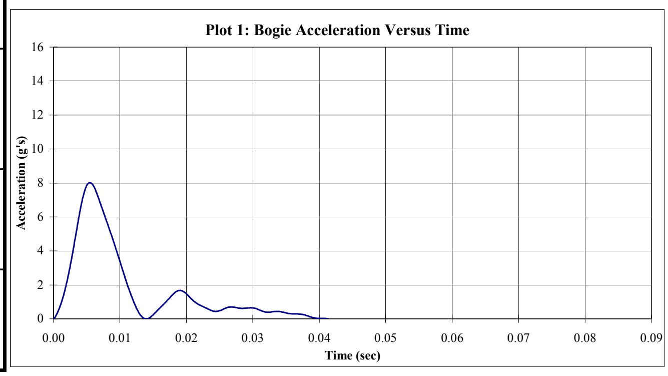
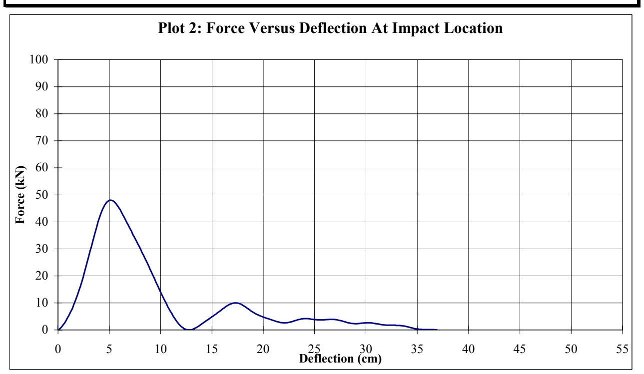


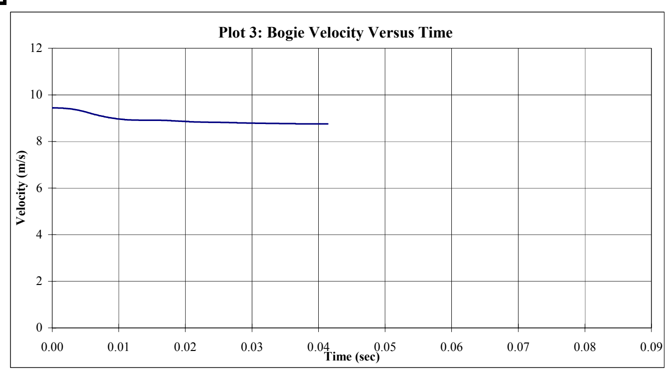
Figure 53. Results of RP-15

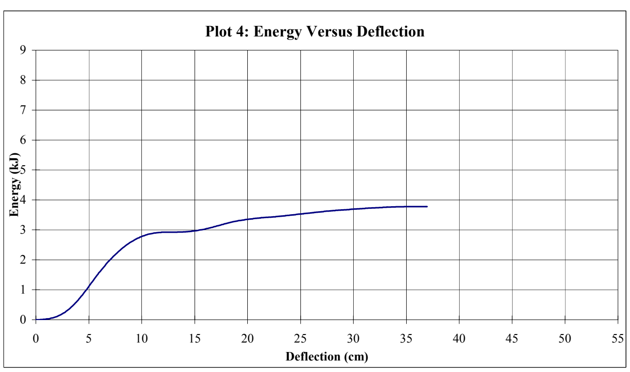
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-16		
Test Date:	26-Jun-2003		
Failure Type:			
Post Properties	No photos		
Post Type:	Visconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	9.4 m/s	(21.1 mph)	(31.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









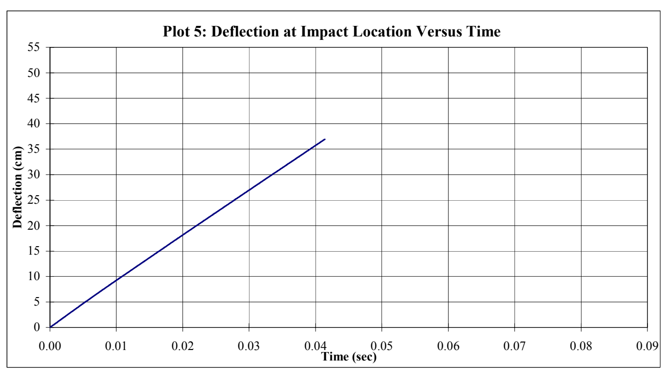
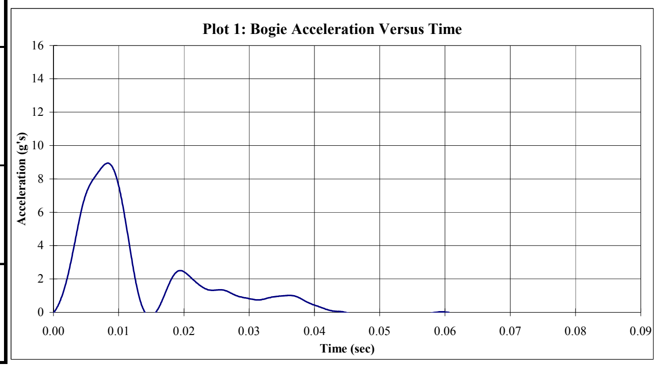
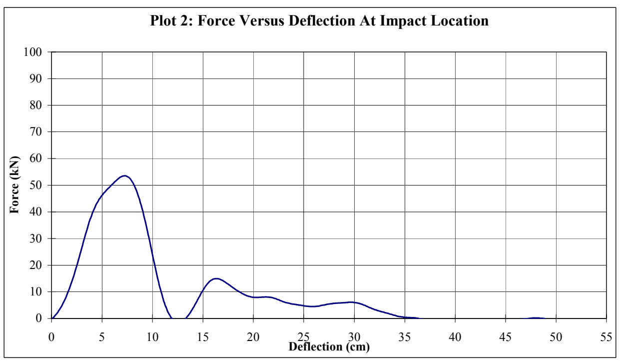
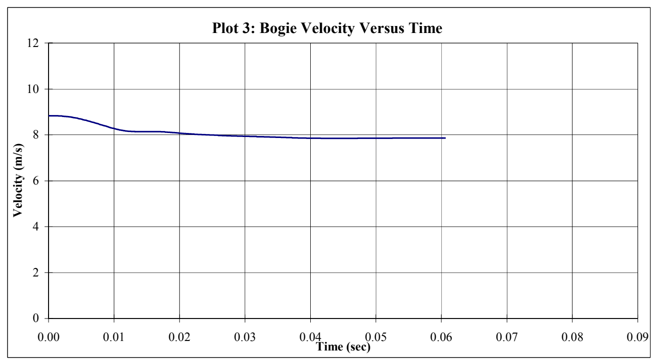


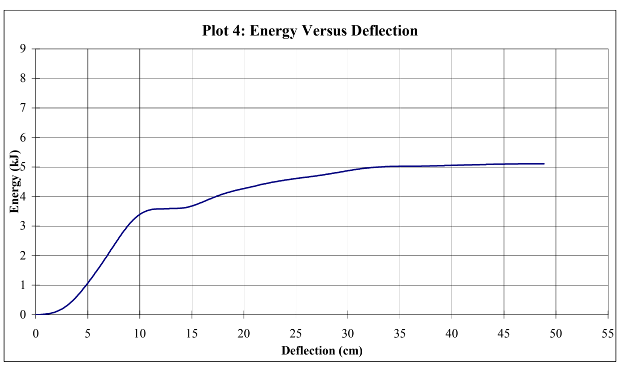
Figure 54. Results of RP-16

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-17		
Test Date:	25-Jun-2003		
Failure Type:	Rings are noticeable in fracture line, long splinters on back side of impact, moderate splinters elsewhere		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.8 mph)	(29.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









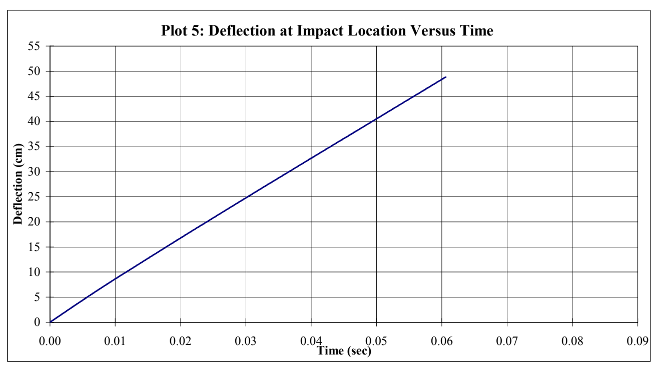
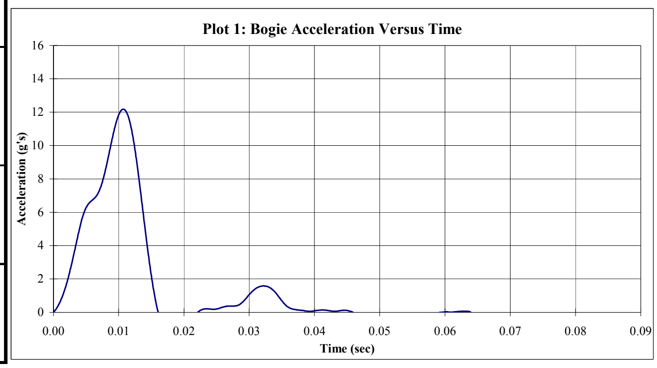
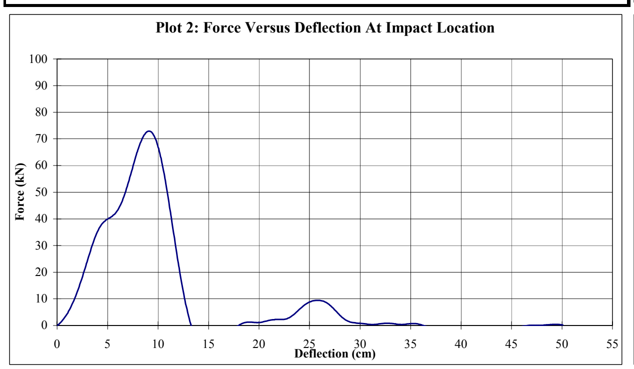
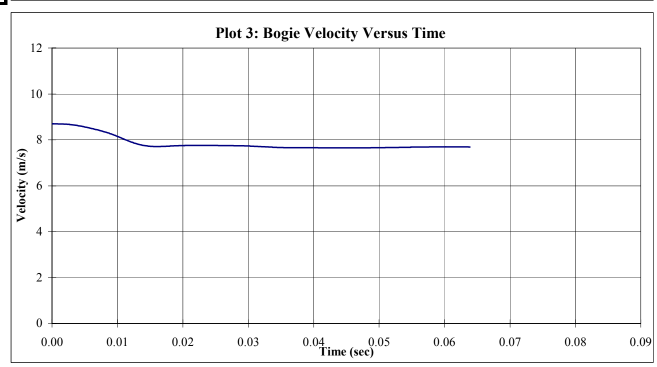


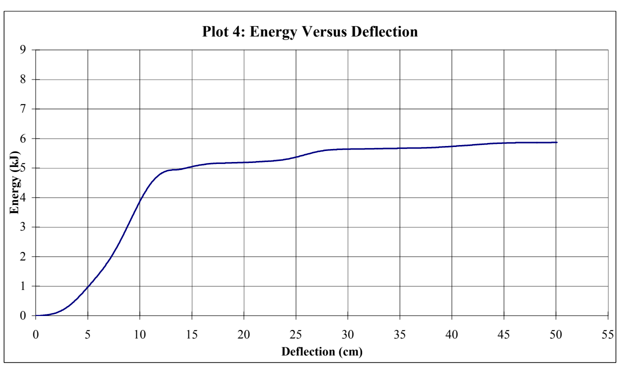
Figure 55. Results of RP-17

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-18		
Test Date:	25-Jun-2003		
Failure Type:	Smooth break along ring line on impact side (possible knot), break line is still jagged vertically		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.5 mph)	(28.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









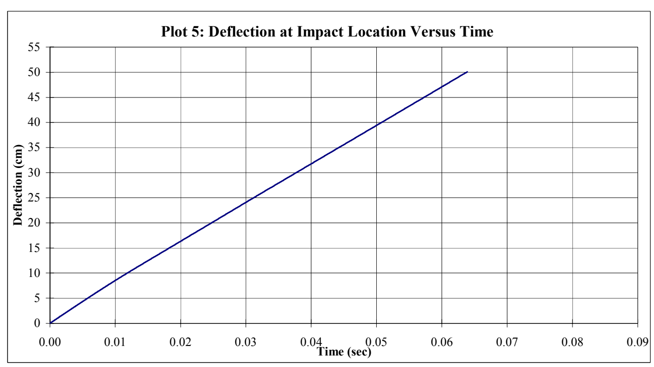
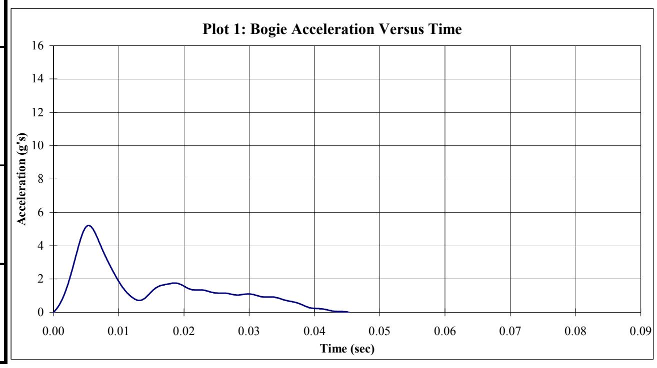
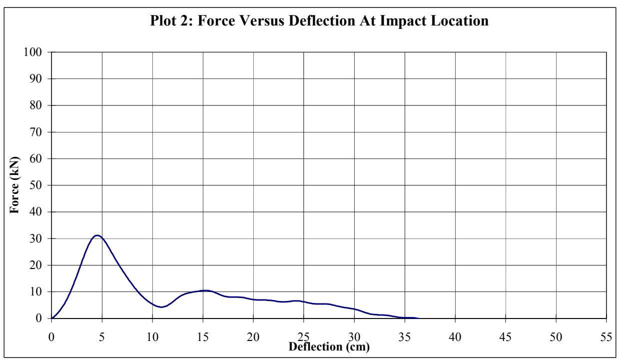


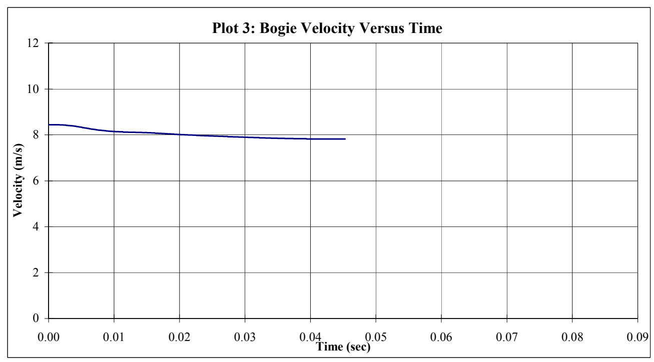
Figure 56. Results of RP-18

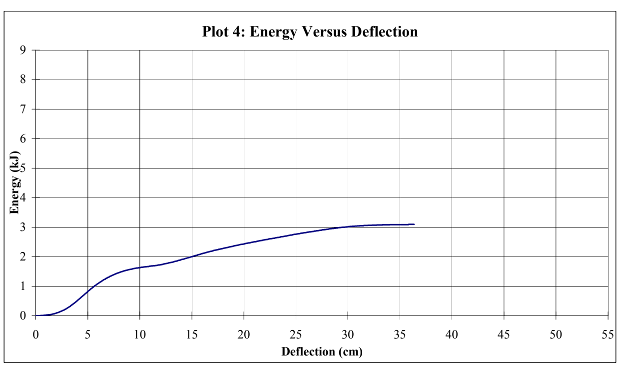
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-19		
Test Date:	25-Jun-2003		
Failure Type:	Ring lines are again noticeable, less jagged than other posts		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric	6" x 8"	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	96.5 cm	(38.0 in)	
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.4 m/s	(19.2 mph)	(27.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









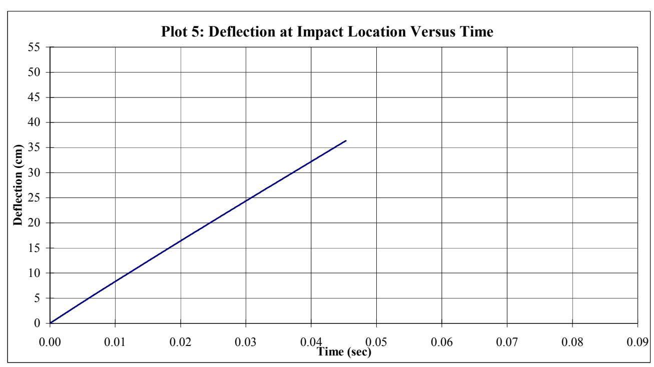
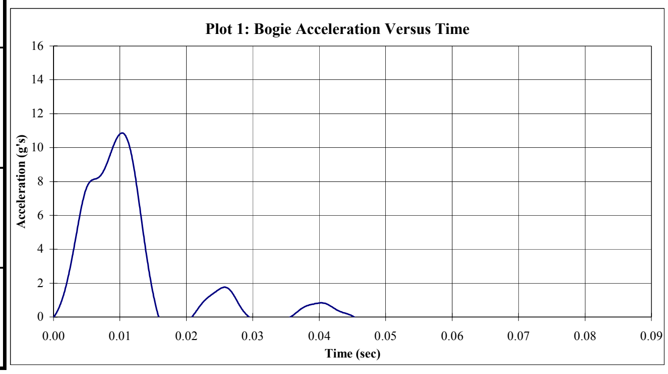
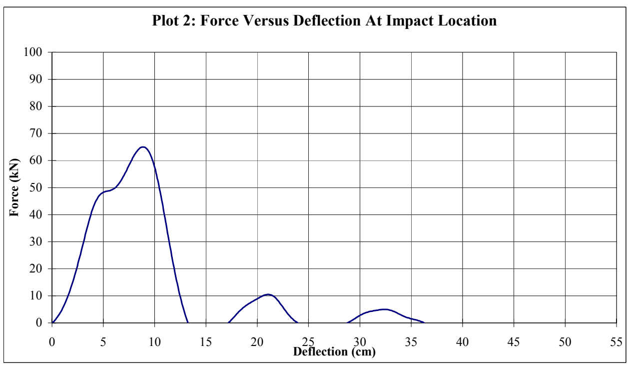
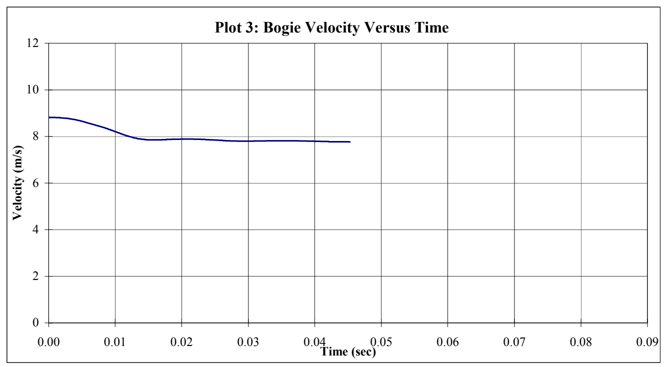


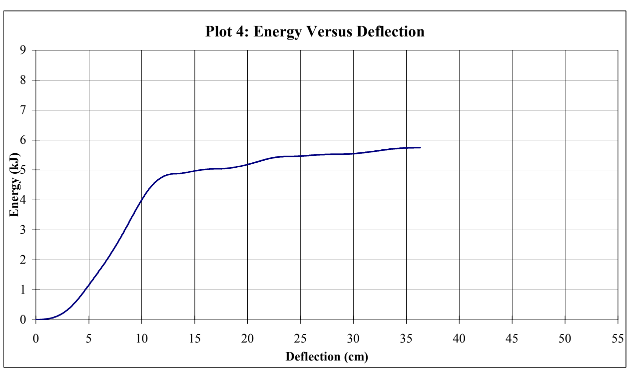
Figure 57. Results of RP-19

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-20		
Test Date:	25-Jun-2003		
Failure Type:			
Post Properties	Very jagged edges, with ring lines noticed		
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(28.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









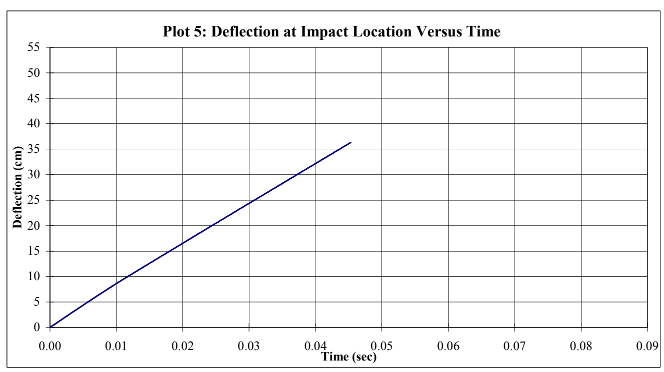
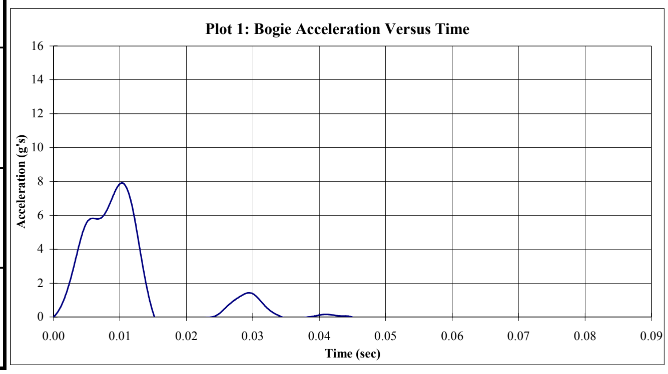
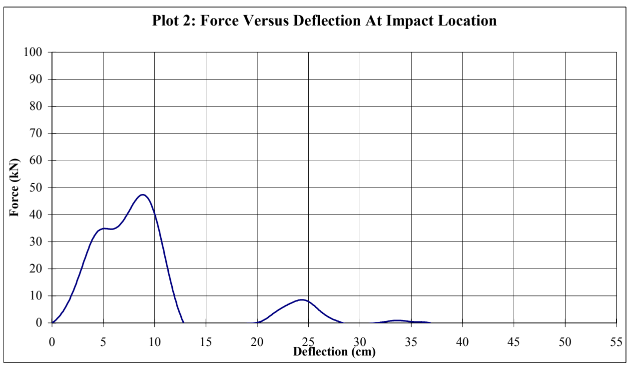


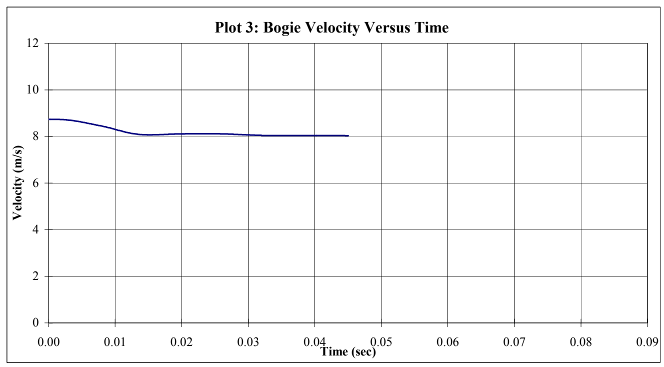
Figure 58. Results of RP-20

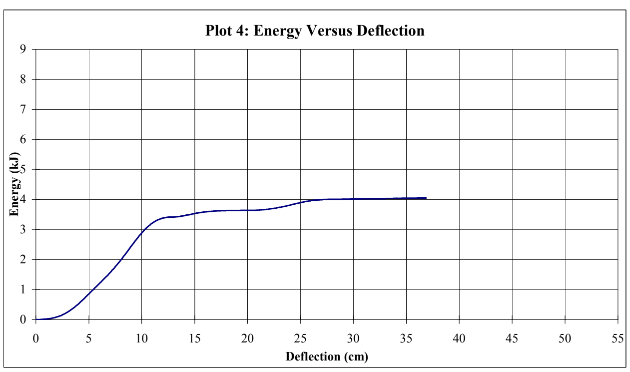
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-21		
Test Date:	25-Jun-2003		
Failure Type:	Break line is smooth along rings and very jagged in one corner, break line appears to be at or above the sleeve		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.5 mph)	(28.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









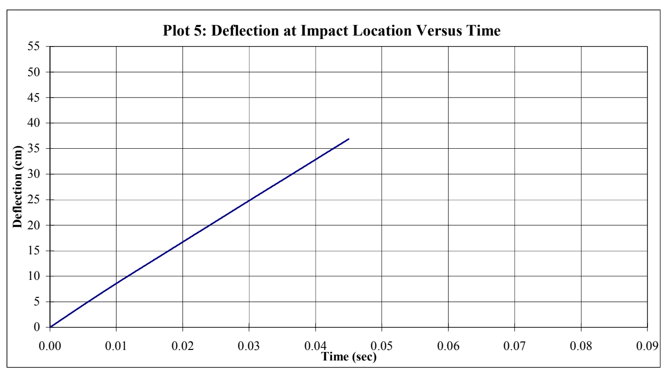
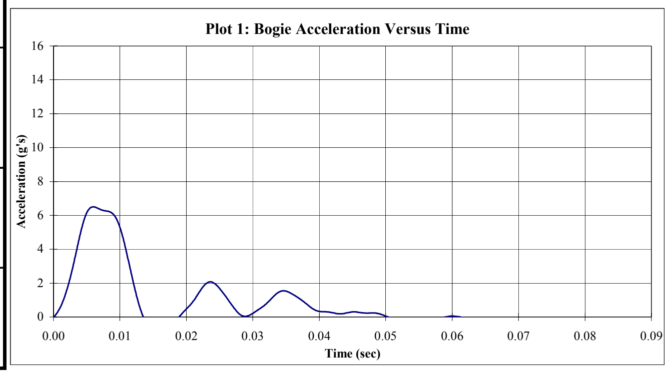


Figure 59. Results of RP-21

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-22		
Test Date:	25-Jun-2003		
Failure Type:	Break line is very level and just below the top of the steel sleeve, break line is very rough with ring lines apparent		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric		6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.5 m/s	(19.0 mph)	(27.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		



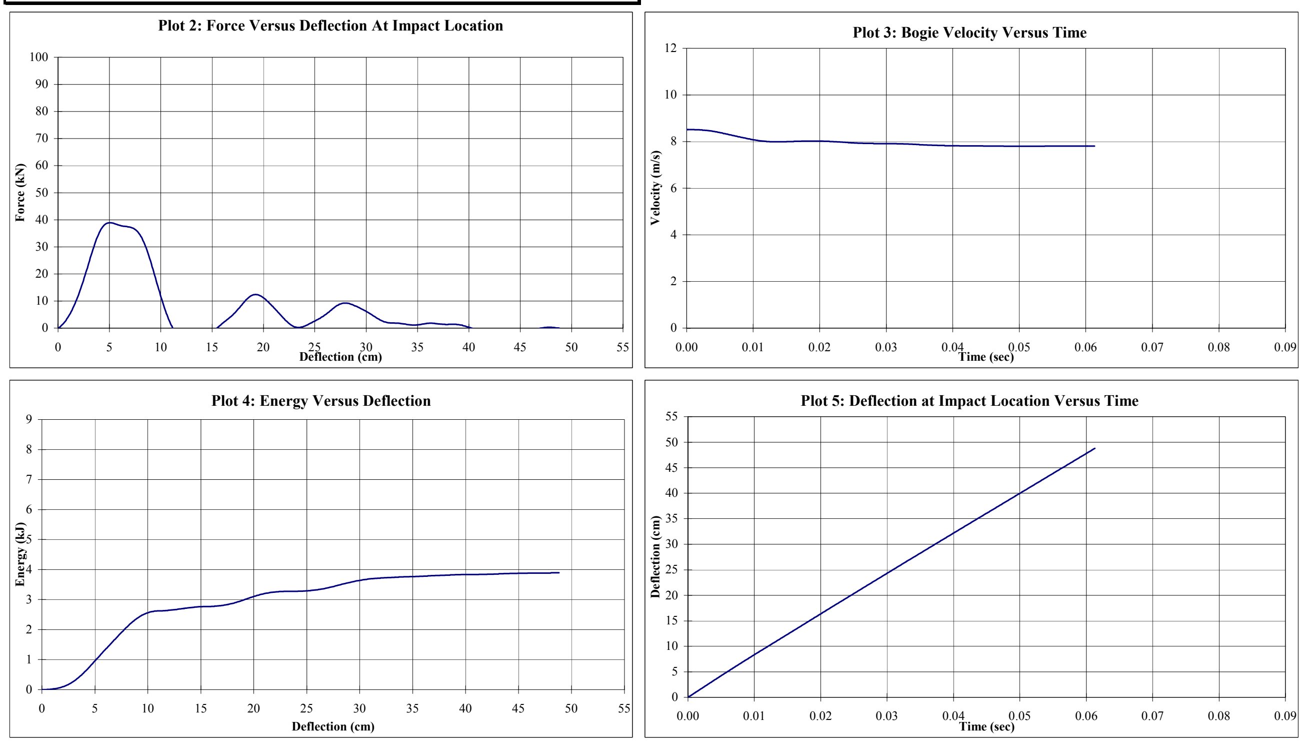
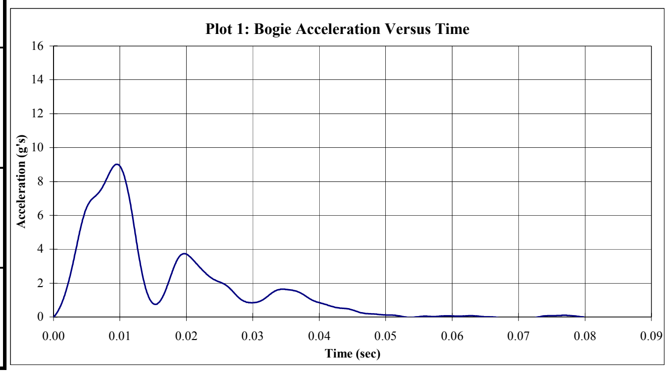
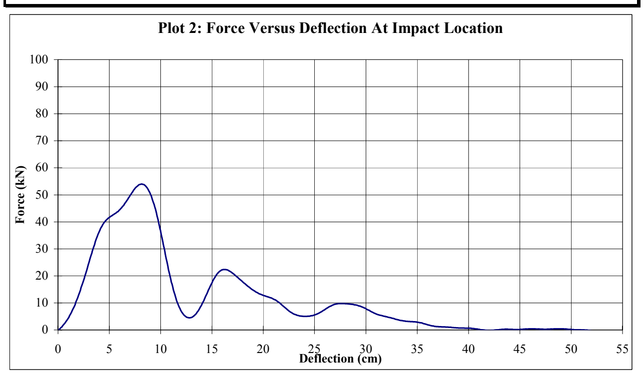


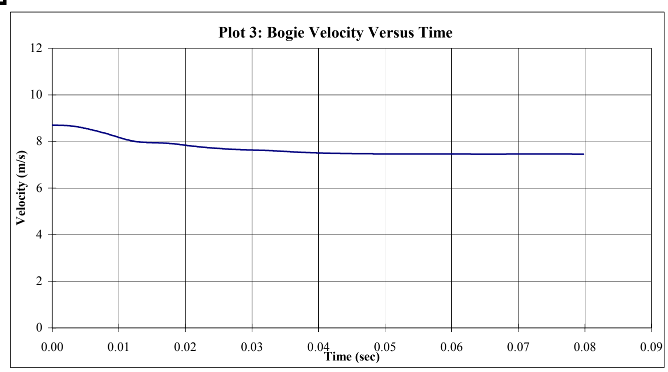
Figure 60. Results of RP-22

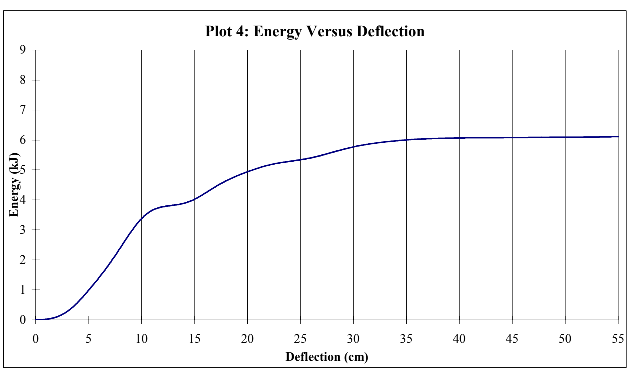
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-23		
Test Date:	25-Jun-2003		
Failure Type:	Fracture line is extremely splintered with very jagged edges, break line is mostly below the top of the steel sleeve		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm metric		6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.5 mph)	(28.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









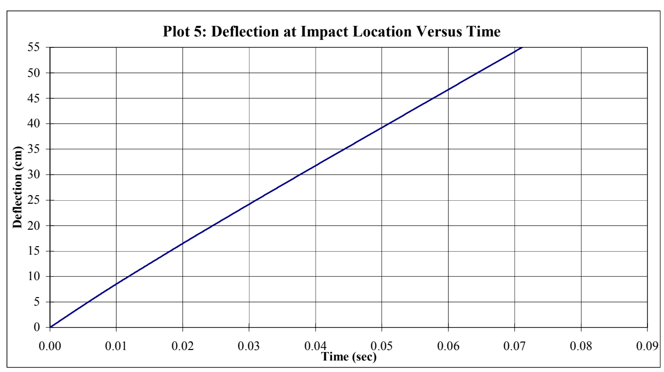
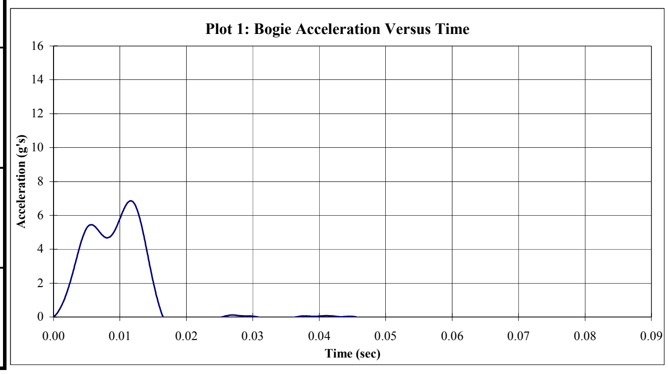


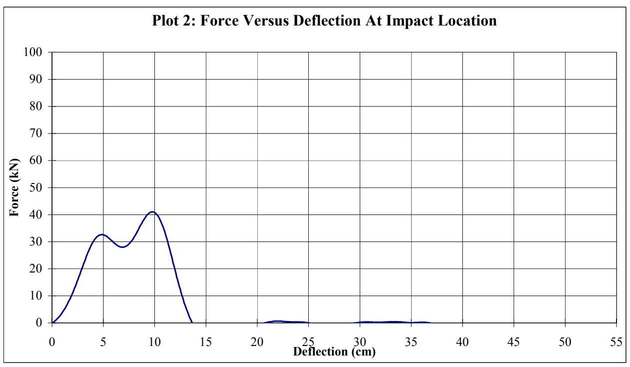
Figure 61. Results of RP-23

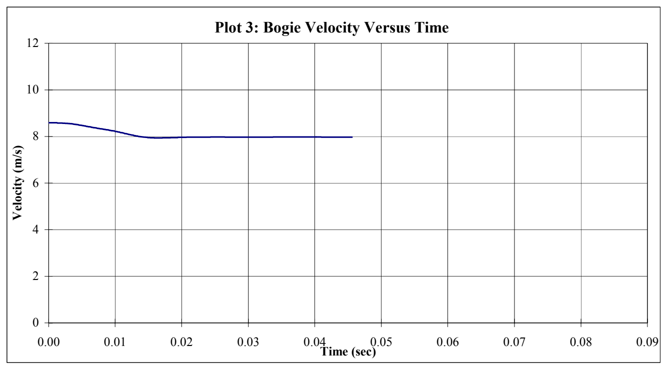
Midwest Roadside Safety Facility

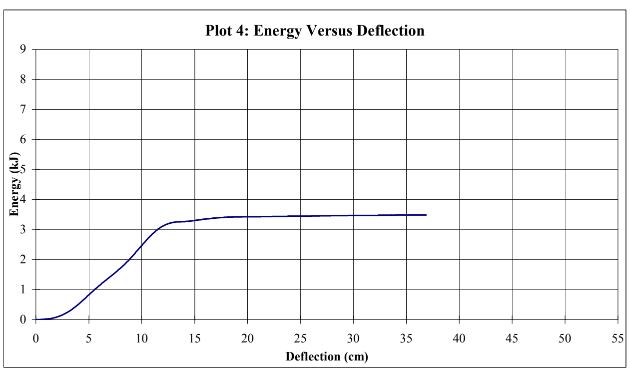
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-24		
Test Date:	25-Jun-2003		
Failure Type:	Short splinters on break line, entire cross section is splintered, fracture line is at ground level		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	8.6 m/s	(19.2 mph)	(28.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









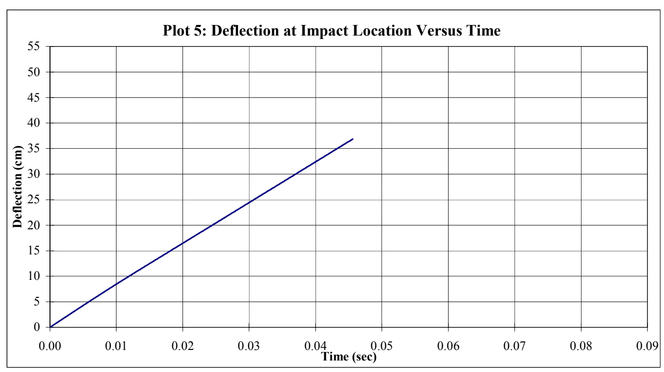
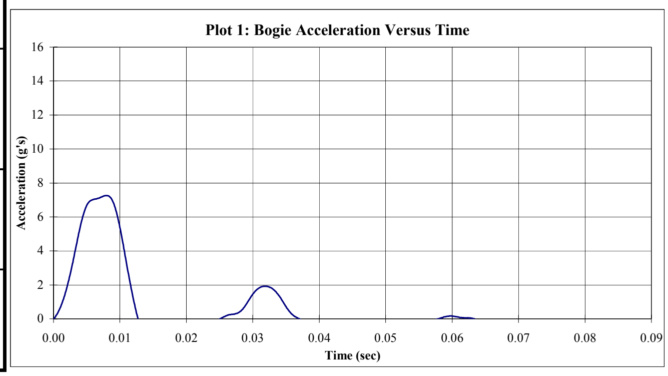
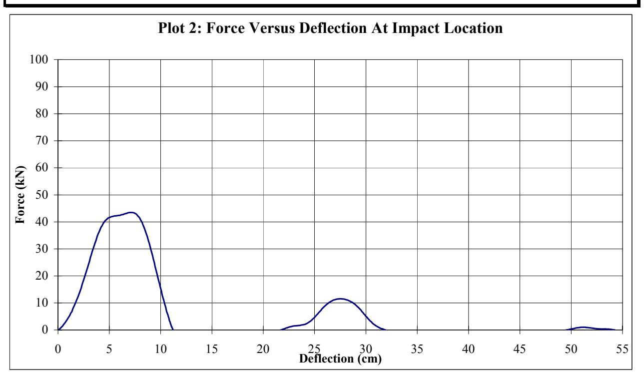


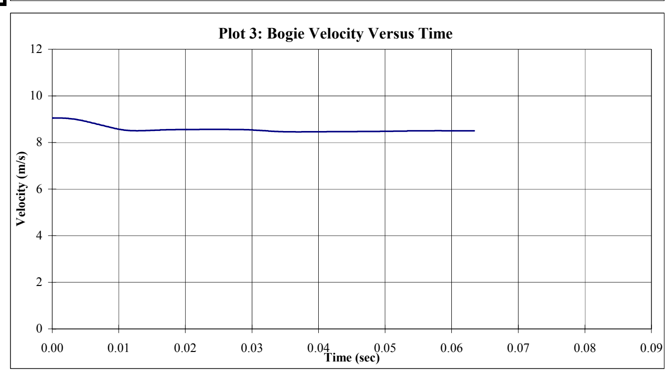
Figure 62. Results of RP-24

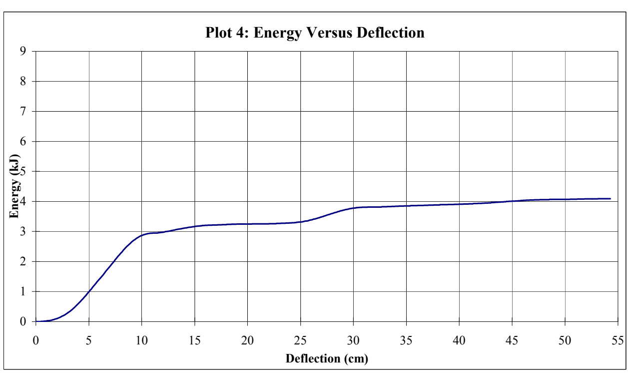
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-25		
Test Date:	25-Jun-2003		
Failure Type:	Long smooth splinters with fracture line below the ground surface		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









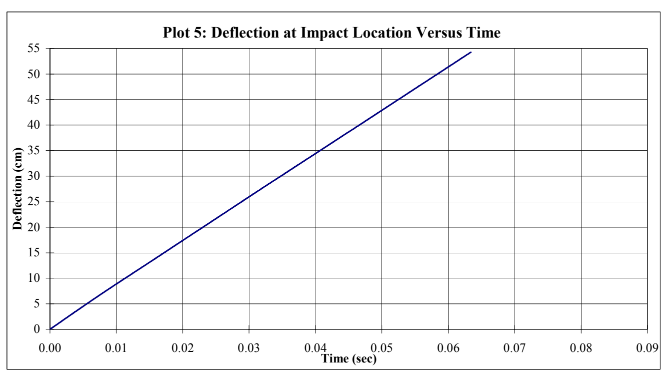
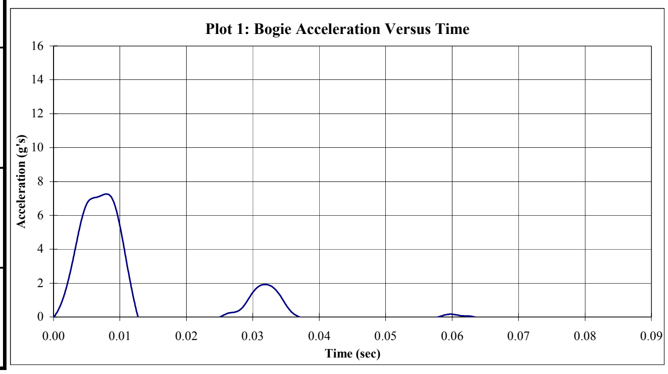
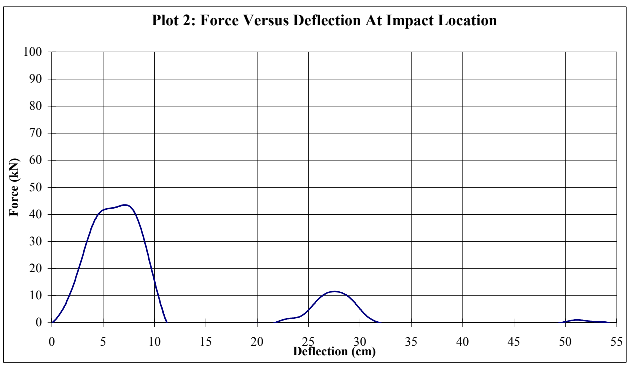


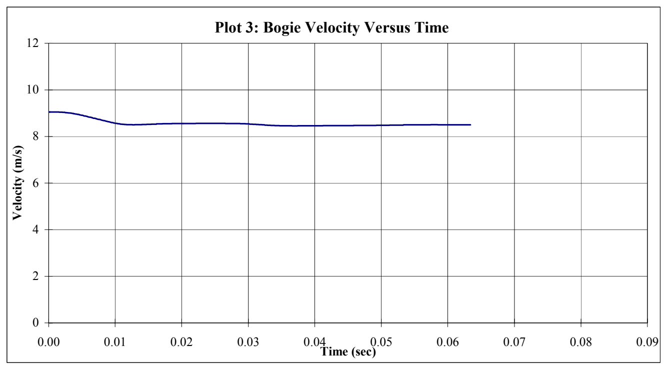
Figure 63. Results of RP-25

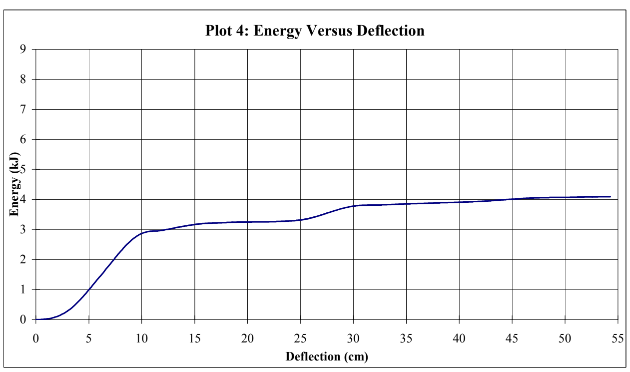
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-25		
Test Date:	25-Jun-2003		
Failure Type:	Long smooth splinters with fracture line below the ground surface		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









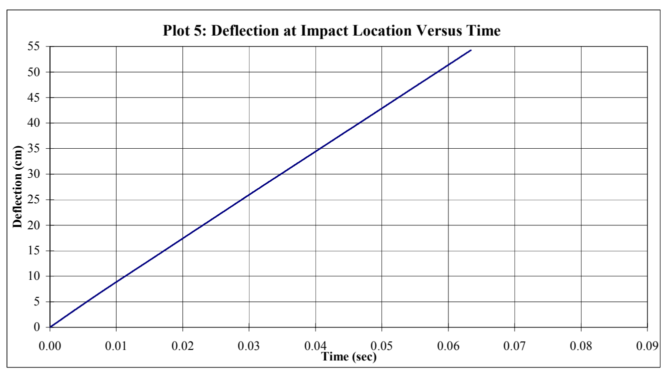
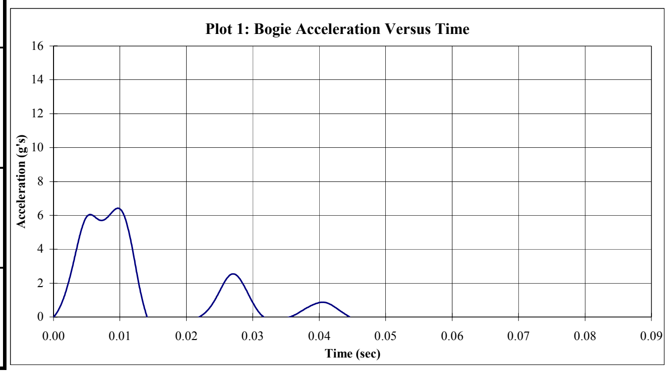
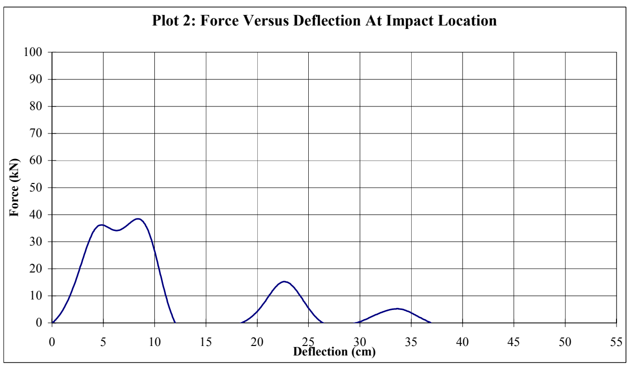
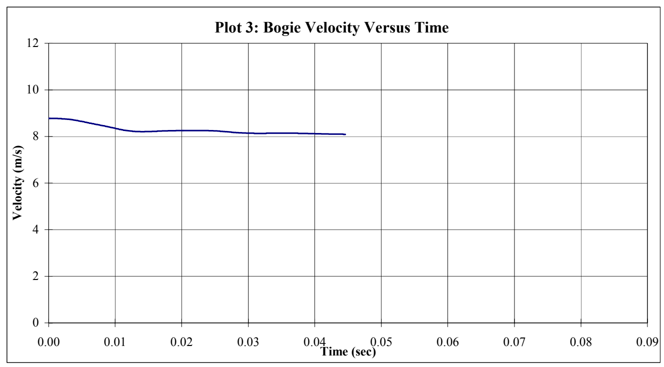


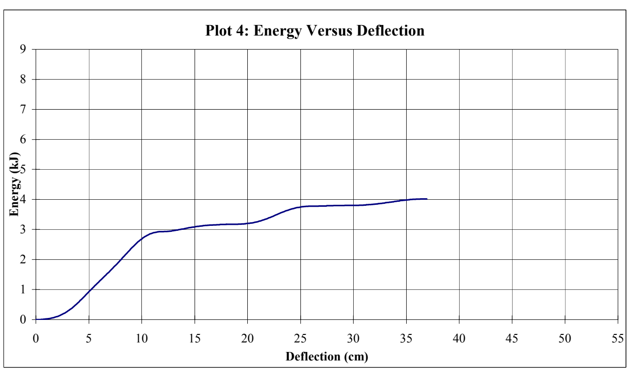
Figure 64. Results of RP-26

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-27		
Test Date:	25-Jun-2003		
Failure Type:	Splinters are less random than RP-26, splinters are somewhat long with ring pattern noticeable, upper an lower still attached		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.6 mph)	(28.8 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









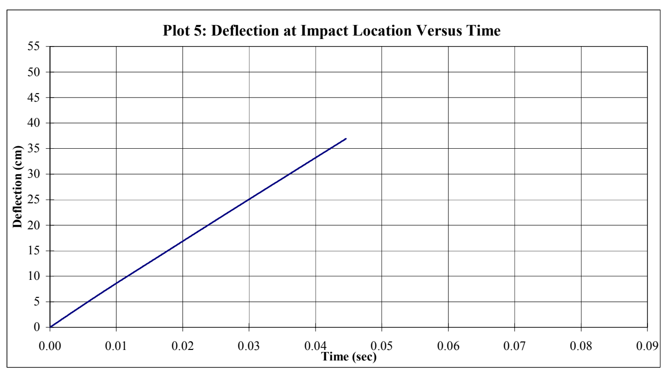
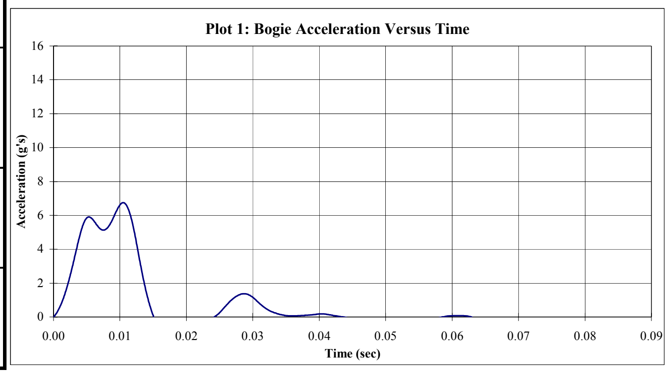


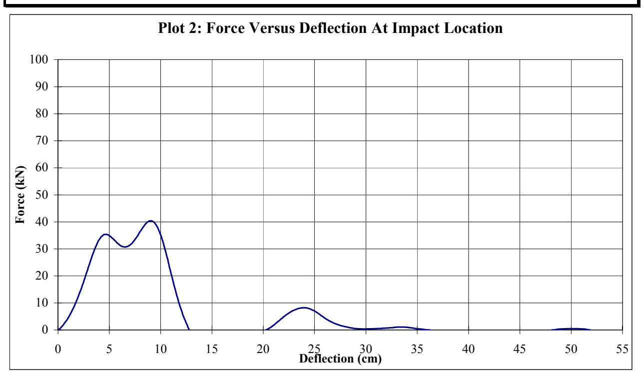
Figure 65. Results of RP-27

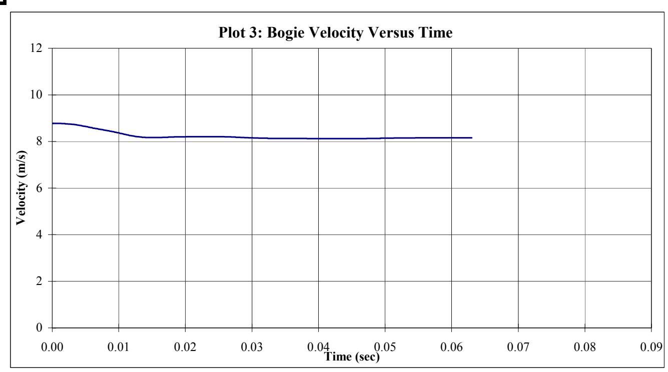
Midwest Roadside Safety Facility

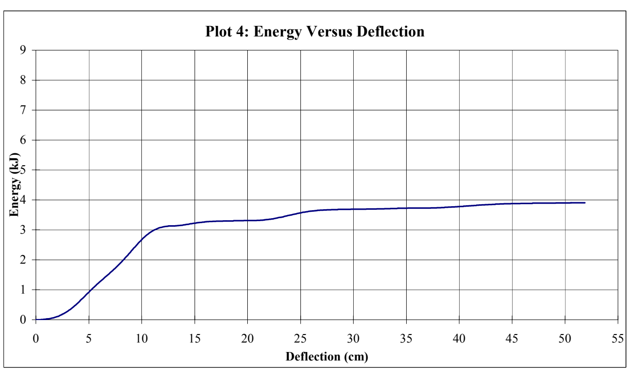
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-28		
Test Date:	25-Jun-2003		
Failure Type:	Fracture line is relatively smooth with long splinters on front and back edges, fracture line is about level with the ground		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.6 mph)	(28.8 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









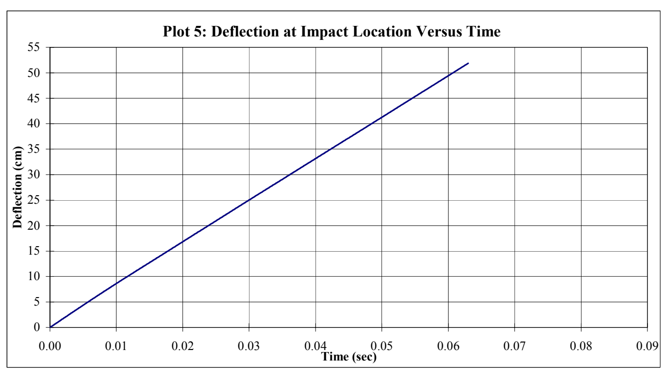
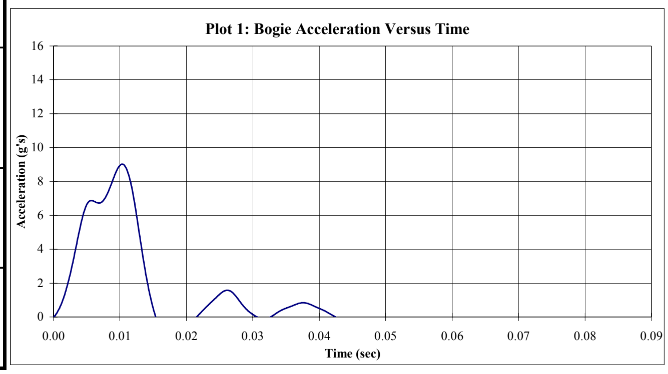
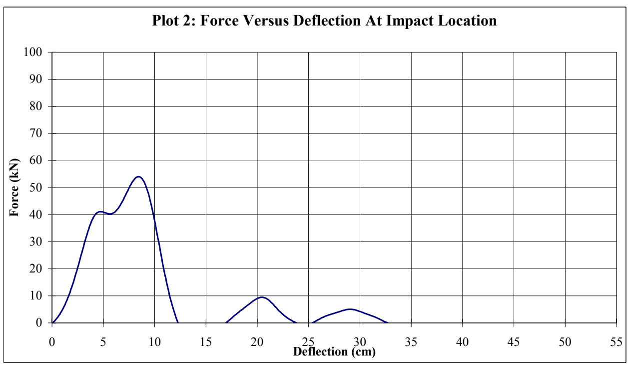


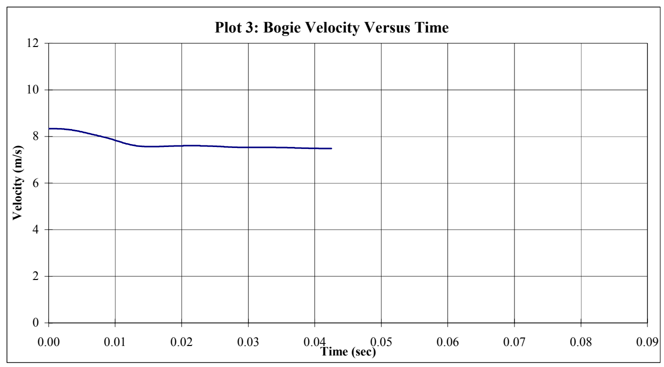
Figure 66. Results of RP-28

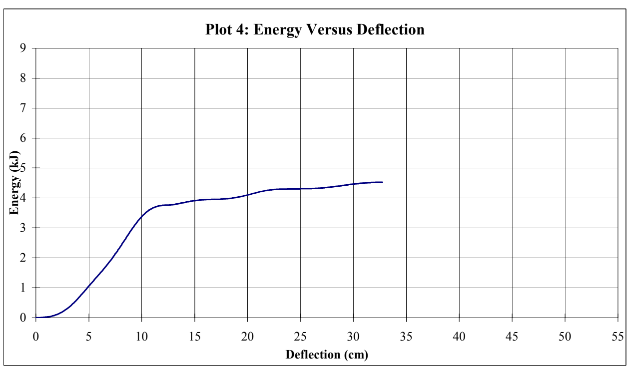
Bogie Test Summary

Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-29		
Test Date:	25-Jun-2003		
Failure Type:	Very long splinters in a quasi conical shape, upper end of fracture line is about ground level		
Post Properties			
Post Type:	Wisconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	8.3 m/s	(18.6 mph)	(27.3 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









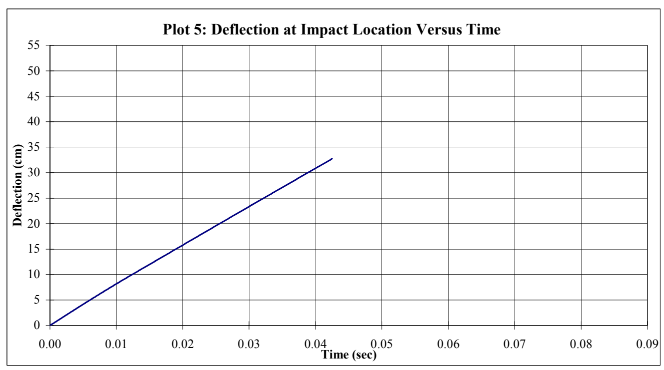
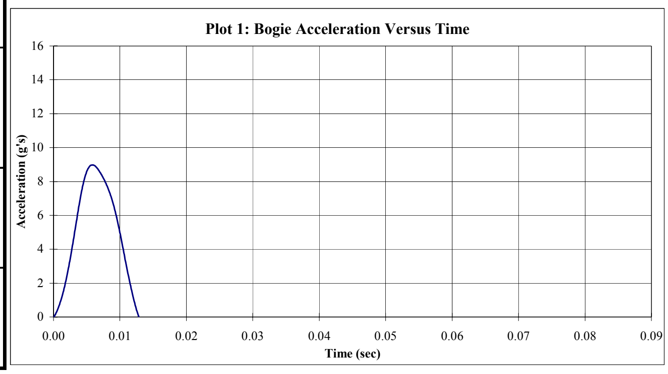
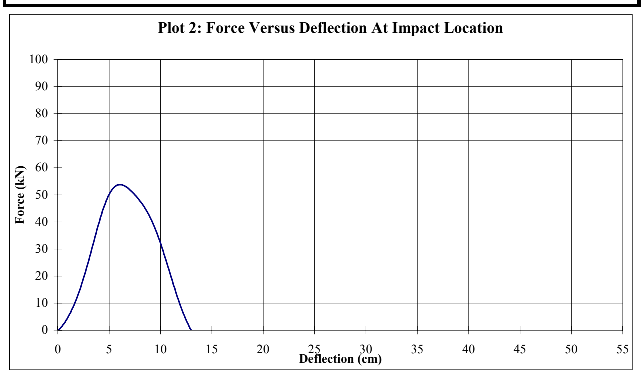
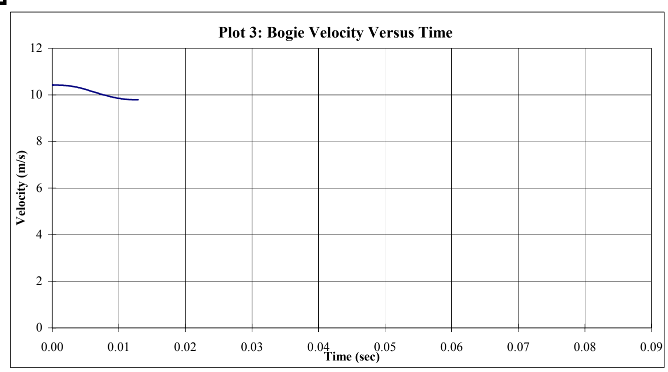


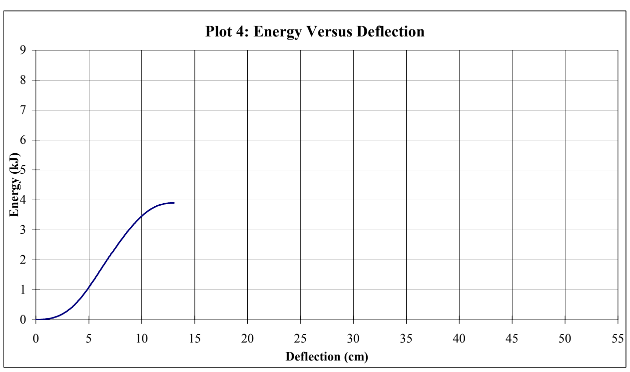
Figure 67. Results of RP-29

Bogie Test Summary			
Test Information	Deep Axis Impact @ 0 degrees		
Test Number:	WISC RP-30		
Test Date:	25-Jun-2003		
Failure Type:			
	Also a quasi conical shape along fracutre, ring lines are very apparent, post has longer splinters at the edges		
Post Properties			
Post Type:	√isconsin Red Pine		
Post Size:	15.2 cm x 20.3 cm	metric	6" x 8"
Post Length:	182.9	cm	(72.0 in)
Embedment Depth:	96.5	cm	(38.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	10.4 m/s	(23.3 mph)	(34.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









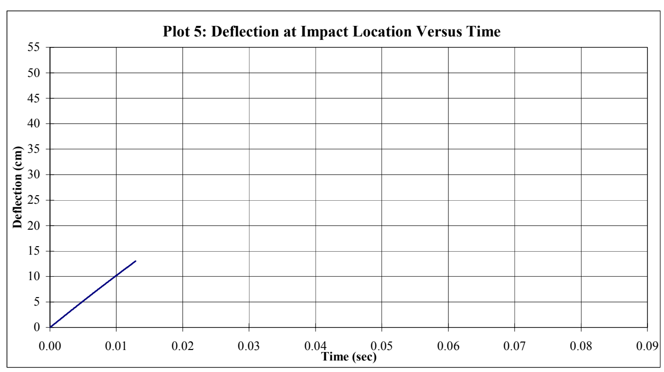


Figure 68. Results of RP-30