INVESTIGATING THE USE OF SMALL-DIAMETER SOFTWOOD AS GUARDRAIL POSTS

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The use of small-diameter softwood as guardrail posts was investigated to offer a lower cost guardrail system to the State Departments of Transportation and open a new market for small-diameter timber which is often the source of devastating forest fires.

The behavior of the round Douglas Fir and Ponderosa Pine posts was evaluated and compared to that of steel posts currently installed on guardrail systems. The diameter of the round posts was adjusted so that they would serve as sufficient substitutes in the barrier system.

Three types of tests were employed to investigate the behavior of round posts: static and dynamic cantilever tests and dynamic soil tests. Shortcomings in the standard wood post testing procedures were identified that could cause the post strength to be overestimated by as much as 50 percent. Revised testing procedures were developed to mitigate the problem.

Results from the testing in combination with results from previous testing and computer simulation indicated that round posts meeting the appropriate size and grading criteria should be adequate substitutes for steel posts currently used in the Midwest Guardrail System. For Douglas Fir, acceptable posts were restricted to those with knots no larger than 51 mm (2 in.) in diameter and a ring density of 6 rings-per-inch or more. The diameter of the Douglas Fir post was recommended to fall between 171 mm (6.75 in.) and 197 mm (7.75 in.). Recommended Ponderosa Pine posts were those with knots no larger than 102 mm (4 in.) in diameter and a ring density of 6 rings-per-inch or more. The diameter of Ponderosa Pine posts must be larger than 197 mm (7.75 in.), but less than 222 mm (8.75 in.).

Two full-scale vehicle crash tests are recommended to verify the adequacy of the longitudinal barrier system, one utilizing 197-mm (7.25-in.) diameter Douglas Fir posts and one utilizing 184-mm (7.75-in.) diameter Ponderosa Pine posts.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

Prompted by the devastating forest fire season of 2000, President Bill Clinton initiated the development of what would become the National Fire Plan. The plan established four main goals: to improve prevention and suppression, reduce hazardous fuels, restore fire adapted ecosystems, and to promote community assistance [1].

One of the most commonly used prevention techniques is fuel management, an idea that has been around for many years. In the 1960's, the U.S. Department of Agriculture (USDA) - Forest Service began managing fuels by using controlled burn techniques [2]. Using these techniques, fires were initiated in areas where they could be contained in order to consume the small-diameter forest thinnings (SDT), most commonly made up of various pine and fir species, that might serve as fuel for fires in the future. Although this method is generally effective, it offers no economic benefits and has high risks.

Today, there are many uses for the small diameter trees that make up the majority of the forest thinnings consumed during controlled burns. Uses for the thinnings include lumber, structural roundwood, wood composites, wood fiber products, compost, mulch, energy, and fuels [3]. The idea is to remove the fuel and sell it for use in various products, hopefully recovering the cost of removing the material. The more products there are, the more likely the cost of removing the SDT will be recovered. Therefore, more uses for small diameter trees must be developed [4].

Guardrail post production is one possible application for SDT that is under consideration. Using SDT's in guardrail systems would provide a new application for thinnings while also reducing the cost of the barrier system.

Guardrail systems constructed on today's roadsides have two main functions. First, they safely redirect vehicles that impact the barrier systems. Second, they dissipate much of the vehicle's kinetic energy during the impact event. Safe redirection prevents the impacting vehicle from contacting the hazard behind the system and also prevents secondary collisions with vehicles sharing the roadway. Energy dissipation reduces the forces applied to the vehicle during the redirection process and thereby reduces the risk of injury to the vehicle's occupants.

The Midwest Guardrail System (MGS) is a specific type of W-beam guardrail that will be used in the study [5-7]. MGS was specifically designed for the high center of gravity vehicles found on today's roadways. The system uses a higher rail mounting height, a shallower post embedment depth, deeper blockouts, and a modified post placement scheme than previous guardrail systems which often fail to perform adequately for the larger and higher vehicles. As with all strong-post W-beam guardrail systems, MGS dissipates energy through the deflection and deformation of the rail and the rotation of the posts in the soil. If the wood posts have insufficient bending strength, the bulk of the impacting vehicle's energy will be absorbed by the W-beam element, thus increasing the tensile force in the rail. If the force increases beyond the capacity of the rail, it will fail, allowing the impacting vehicle to pass through. Therefore, the posts must have sufficient structural capacity to displace founding soils and absorb energy.

1.2 Objective

The objective of the research project was to determine the properties of the Douglas Fir and Ponderosa Pine wood species when used as round posts under impact loading conditions. The primary goal of this research was to determine an acceptable diameter and grading specification for the two species in order to allow these species to serve as substitutes for the rectangular Southern Yellow Pine and wide-flange steel posts currently used in guardrail applications.

1.3 Research Approach

As discussed in Section 1.1, historical testing has shown that wood posts should generally have sufficient strength to rotate in the soil without fracturing. Hence, identifying the necessary size and wood grading criteria to assure such behavior was the most important task of the research described herein.

BARRIER VII [8], a computer simulation program was utilized to establish failure criteria for the MGS system, and an acceptable level of risk for that failure was defined. Once an acceptable level of risk had been established, the results of physical testing could be compared with results from soil bogie tests conducted on the standard steel post used in the MGS system. Based on those comparisons, the diameter of the wood posts could be selected to be capable of developing the capacity that was required to meet the established level of reliability.

A series of dynamic and static cantilever tests was conducted to develop a preliminary post diameter. In order to complete the testing, a sample of posts was collected for each species. Each specimen in the sample was required to meet a general grading criterion that is presented in Appendix F.

The general grading criteria pertain mostly to the manufacturing methods and manufacturing defects. The criteria were specified to prevent damaged or poorly processed products from being used in a guardrail system based on those parameters established for wood poles by the American National Standards Institute (ANSI) in ANSI 05.1 [9]. Specific changes were made to the limits on manufacturing methods, scars, shape, straightness, splits, shakes, decay, holes, slope of grain, and compression wood.

The total sample was composed of two sub-samples, sample A and sample B. Sample A was made up of posts falling into three categories based on variation in knot locations and sizes, and ring density. Sample B was randomly selected. Dynamic and static testing was conducted on sample A, and static testing was conducted on sample B.

When an approximate diameter had been determined from the first set of tests, a second set of cantilever tests was conducted on a sample of posts that were selected in the same manner as before. The second set of cantilever tests was conducted to evaluate and verify the capacity of posts with the adjusted diameter. Based on the results of the second set of tests, the required post diameter and wood grading specifications were adjusted as needed to develop the desired capacity.

When the post diameter had been finalized, dynamic soil bogie tests were conducted to verify that the diameter was large enough to give the posts sufficient capacity to rotate in the soil rather than fracture. Since this was not the case, the diameter of the posts was increased based on the results, and a second set of soil bogie tests was conducted. The second set of tests verified that the new diameter was large enough, and the results of the soil tests were used in BARRIER VII computer simulations to evaluate the effectiveness of the barrier. The simulations showed that the posts should be adequate, and a full-scale test was recommended for both species.

This thesis is divided into 15 chapters plus references and appendices. The first chapter serves as an introduction and overview of the project. Chapter 2 contains a comprehensive literature review and overview of the grading criteria for wood posts. Chapter 3 contains a thorough explanation of the sampling and documentation procedures used for the testing specimen. It also includes summaries of properties recorded for each post.

Chapters 4 and 5 contain information from the first round of dynamic testing. Chapter 4 describes the physical testing setup, includes the round 1 bogie testing matrix, and presents the details of the testing including information on the devices used to record impact events, data processing methods, and wood post details. Chapter 5 presents the results of the first round of tests.

In Chapter 6, the diameter for the second round of testing is selected based on the results of the first round of testing and some initial computer simulation modeling. Chapter 7 describes the flaws discovered in the bogie testing methods, the effects they can have, and the possible solutions to remedy the problem. Chapters 8, 9, and 10 describe the second set of cantilever sleeve testing and results.

Chapter 11 discusses modifications in the diameter requirements based on the results from the second round of testing. The process of testing the candidate post sizes in soil is described in Chapter 12, and Chapter 13 presents computer simulation findings with the final Ponderosa Pine and Douglas Fir post size recommendations. Finally, Chapter 14 summarizes the study and its findings and presents a recommendation for future work.

2 LITERATURE REVIEW

2.1 Prior Wood Post Testing

A limited amount of research has been conducted on round wooden posts. This section is a summary of those studies and results that are relevant to this project.

2.1.1 Static and Dynamic Post Testing

Beginning in 1960, Graham et al. [10] conducted a six-year program to develop revised standards for the state's traffic barriers. Both bogie and full-scale tests were conducted to identify the capacity and safety performance of various guardrail posts in rigid foundations and soils. The bogie test results are presented in Table 1.

Table 1. Dynamic Post Strength

Post	Force	Max. Resistance (lb.)					
		Fine Sand	Speed (mph)	Glacial Till	Speed (mph)	Concrete	Speed (mph)
Steel S3x5.7	Lateral					5800	20
						5400	10
	Longitudinal					1500	20
						2000	10
3 in. by 2 in. by 3/16 in. Steel Tube	Lateral					3700	20
						4100	20
	Longitudinal					2500	20
						2900	10
2.25 in. by 2 in. by 4.1 lb/ft Steel Right of Way Fence Posts	Lateral					4700	10
	Longitudinal					2100	30
						2400	30
Steel W6x8.5	Lateral	5500	20	13100	20		
		3800	10	10200	20		
		6200	10	7800	10		
	Longitudinal	3800	20	4500	20		
		3000	20	4500	20		
		3800	20	4600	20		
		3600	10	3800	10		
Cedar (6 in. by 8 in.)	Lateral	5800	20	10400	20		
		4800	10	7100	20		
				8400	10		
	Longitudinal	5800	20	9500	10		
		6600	20	7000	10		
		5200	10	6700	20		

In 1961, Cichowski et al. [11] conducted several static post tests and full-scale crash tests at the General Motors Proving Ground. Static post tests were conducted on both the weak axis (side impact) and the strong axis (front impact) of concrete, steel, and rectangular wood posts. The maximum measured breaking strength for each type of post is listed in Table 2. A 457-mm (18-in.) load height was used for all of the tests.

Table 2. Static Post Breaking Strength

Post Type	Size	Treatment/Details	Details	Side Impact (lbs)	Front Impact (lbs)
Wood	6 in. x 8 in.	No Treatment		23500	23900
		4 Yrs. Pressure		21500	24100
		5 Yrs. Pressure		21200	25700
		6 Yrs. Dipped		13000	16000
Steel		6 x 4 in. - I Beam		3700	1300
Concrete	6 in. x 8 in.	1/2 in. Vertical Rebar	1/4 in. Horizontal Rebar	5800	8200
			3/8 in. Horizontal Rebar	5800	7800
		5/8 in. Vertical Rebar	1/4 in. Horizontal Rebar	4300	9700
			3/8 in. Horizontal Rebar	4600	10500

In a study conducted by Michie and Gatchell in 1974 [12], southern pine, red oak, and steel posts were tested with a pendulum. The testing showed that 152 mm x 152 mm (6 in. x 6 in.) and 152 mm x 203 mm (6 in. x 8 in.) wood posts have qualities equal or superior to those of W6x8.5 and S3x5.7 steel posts. They also concluded, similar to Rohde and Reid, that the performance of wood posts greatly depends on the location of knots. In their report, Michie and Gatchell suggested selecting posts based on the grain distortion caused by knots, avoiding knots that distort the grain in the tension face for more than a third of the width of the face.

Also in 1974, Michie, Gatchell, and Duke [13] performed dynamic tests on both round and rectangular wood posts of varying species and sizes fixed in a sleeve with an impact height of 610 mm (24 in.). Sizes ranged from 102-mm x 102-mm (4-in x 4-in.) to 203-mm x 203-mm (8-in x 8-in.), and included both rectangular and round cross-sections. The species tested consisted of Douglas Fir, Red Pine, Red Oak, and Southern Pine. Although no soil interaction was taken into account, the researchers concluded that the specific shape has little influence on results stating, "…the engineer can use sawed or round material and expect equal performance for equal moments of inertia." Results from the experiment are shown in the Table 3 and Table 4 for round and rectangular post data, respectively.

Table 3. Dynamic Post Testing Results by Michie

Species	Nominal Width (in.)	Nominal Depth (in.)	Peak Force (kips)	Average Force (kips)	Fracture Energy (ft-kips)
Red Oak	4.0	4.0	5.5	2.6	2.18
	4.0	6.0	10.9	5.5	4.05
	6.0	6.0	11.6	5.1	3.54
	6.0	8.0	22.0	7.9	7.42
Southern Pine	4.0	6.0	8.2	3.6	2.35
	6.0	6.0	10.0	3.8	2.80
	8.0	8.0	26.1	10.1	11.80
Douglas Fir	4.0	4.0	5.5	2.6	2.18
	4.0	6.0	10.9	5.5	4.05
	6.0	8.0	11.6	5.1	3.54
	8.0	8.0	22.0	7.9	7.42

Table 4. Dynamic Post Testing Results for Red and Southern Yellow Pine Species

	Diameter (in.)	Peak Force (kips)	Avg. Force (kips)	Fracture Energy (ft-kips)
Southern Yellow Pine	9	16.8	7.2	5.46
Red Pine	6.10	4.1	2.2	0.92
	6.50	7.9	3.9	1.99
	6.60	5.7	2.8	1.28
	6.75	8.0	3.8	1.99
	7.25	12.0	6.5	3.50
	8.60	16.0	9.1	4.45
	9.10	17.1	10.3	5.66
	9.30	21.4	9.8	7.65
	6.50	8.1	3.6	1.81
	7.00	11.1	6.3	3.50
	7.00	6.5	2.7	1.81
	7.25	7.4	2.9	2.16
	7.75	16.8	11.7	6.50
	8.15	13.2	7.6	3.99
	8.50	21.3	20.5	10.57
	9.75	19.8	12.4	6.23

In 1978, Calcote et al. [14] studied the effects of soil on the performance of guardrail posts. Eighty pendulum tests were conducted on steel and wood posts in four different types of soil. As a control value, the tests were also conducted with posts in a fixed support. For this experiment, 152-mm x 203 mm (6-in x 8 in.) Douglas Fir posts were used with an 889-mm (35-in.) embedment depth. The mode of failure for all strong axis tests was soil yielding. For the weak-axis tests, the failure mode was generally post fracture with the exception of the saturated clay test in which the soil failed first.

Another study by Jeyapalan et al. [15] in 1984 compared 178-mm (7-in.) round Southern Yellow Pine (SYP) posts to W152x12.6 (W6x8.5) steel posts. In the study, three static tests were conducted for each of two types of soil, cohesive and cohesionless. Of the three tests in each soil type, two were steel posts embedded at depths of 1118 mm (44 in.) and 965 mm (38 in.), and one test consisted of a round wood post embedded at

965 mm (38 in.), all with a load height of 533 mm (21 in.). From these tests, the researchers concluded that round wood posts and steel posts perform very similarly. In the cohesive soil test, the 1118-mm (44-in.) deep steel post had nearly identical results to the 965-mm (38-in.) deep wooden post. The peak force and energy dissipated by the wood post were 16.5 kN (3.7 kips) and 5.7 kJ (50.4 kip-in.), respectively, while the equivalent values for the steel post were 16.9 kN (3.8 kips) and 5.8 kJ (51.6 kip-in.), respectively. The 965-mm (38-in.) deep steel post test resulted in 14.7 kN (3.3 kips) and 5.2 kJ (45.6 kip-in.) respectively, approximately 10 percent less than that observed for the round wooden post. In the cohesionless soil, the 1118-mm (44-in.) deep post surpassed the round post in both peak force and energy by about 20 percent, with a peak force of 17.3 kN (3.9 kips) and an energy value of 7.0 kJ (62.4 kip-in.). The 965-mm (38-in.) deep steel post, however, showed a higher peak force, 14.7 kN (3.3 kips), but a lower amount of absorbed energy, 5.7 kJ (50.4 kip-in.), than the round post.

In the dynamic tests in cohesive soil, the steel post's performance exceeded that of the wooden post in both peak force and total energy absorbed. Peak force for the steel post was 76 kN (17 kips) while the wood post's peak force was 73 kN (16 kips). The energy absorbed was 40.5 kJ (359 kip-in.) for the steel post and 36.9 kJ (326 kip-in.) for the wood post. A comparison for the cohesionless soil was not available due to the wood post fracturing almost immediately.

Based upon these static and dynamic tests, the researchers concluded that steel posts are sufficient substitutes for round posts used in guardrail systems found in Texas. The authors did caution that more tests should be completed in the future.

Bronstad et al. [16] conducted a study in 1988 on bridge rail transitions. A total of twelve pendulum tests were performed on both wood and steel posts. The impact height was 533 mm (21 in.) with a 1814-kg (4000-lb) pendulum. The different types of steel posts were tested at an embedment depth of 1118 mm (44 in.), with and without a 460 mm x 610 mm (18 in. x 24 in.) soil paddle, while the various sizes of wood posts used a 914-mm (36-in.) embedment depth. The results, presented in Table 5, showed two important findings: (1) the soil paddle does not make a significant difference in the stiffness or maximum force and (2) the W6x15.5 posts are nearly as stiff as the 254-mm x 254-mm (10-in x 10-in.) wood posts.

Table 5. Southwest Research Institute Pendulum Test Results

Test Category	Post Type	Maximum Force (Kips)	Avgerage Stiffness (k/in.)	Total Impulse (k-sec.)	Failure Type
Square	12 x 12 in. Wood	20.7	3.41	2.274	Soil Yield
	12 x 12 in. Wood	23.8		2.271	Soil Yield
	10 x 10 in. Wood	16.3	2.55	1.544	Soil Yield
	10 x 10 in. Wood	16.4		NA	Post Fracture
	8 x 8 in Wood	13.2	1.67	1.287	Soil Yield
	8 x 8 in Wood	11.6		1.091	Soil Yield
Strong Axis	W6x15.5 With paddles	20.4	2.4	2.475	Soil Yield
	W6x15.5 With paddles	18.3		2.45	Soil Yield
	W6x15.5 Without paddles	19.2	2.28	2.637	Soil Yield
	W6x15.5 Without paddles	17.3		2.215	Soil Yield
	W6x8.5	12.7	2.46	0.572	Soil Yield
	W6x8.5	12.7		0.879	Soil Yield
	W6x8.5	10.2		0.5	Soil Yield
	W6x8.5	8.3		0.667	Soil Yield
	6 x 8 in. Wood	11.7	1.56	0.699	Soil Yield
	6 x 8 in. Wood	6.4		0.514	Soil Yield
	6 x 8 in. Wood	7.3		0.529	Soil Yield
	6 x 8 in. Wood	7.2		0.437	Soil Yield
Weak Axis	W6x15.5	10.8	1.3	1.74	Post Yield
	W6x15.5	10.5		1.717	Post Yield
	W6x8.5	4.8	1.15	0.28	Post Yield
	W6x8.5	4.1		0.243	Post Yield
	W6x8.5	5.1		0.287	Post Yield
	W6x8.5	4.3		0.284	Post Yield
	6 x 8 in. Wood	11.2	1.95	0.154	Post Fracture
	6 x 8 in. Wood	6.5		0.103	Post Fracture
	6 x 8 in. Wood	8		NA	Soil Yield
	6 x 8 in. Wood	11.1		0.186	Post Fracture

In 1995, Rohde and Reid [17-19] studied grading specifications and requirements for wood posts in W-beam guardrail. The authors noted that the grade of a post was significantly influenced by wane, missing wood on the corners of the post, even when it was located at the ends of the posts where it has little or no influence on performance. To deal with this problem, the posts were graded twice, once according to the Southern Pine Inspection Bureau (SPIB) standards [20] and a second time without considering wane on the ends of the posts. This re-grading significantly altered the grade of many posts.

After completing static and dynamic tests, the researchers concluded that there was no significant benefit achieved by requiring Grade 1 SPIB posts and suggested lowering the requirement to Grade 2 with the wane and knot criteria relaxed at the ends of the posts. The results were believed to effectively lower the costs of guardrail installations without adversely impacting its safety performance.

In 1996, Holloway et al. [21] conducted a study to evaluate a deeper post embedment. In this study, the researchers examined the use of a 1270-mm (50-in.) embedment depth as opposed to the standard 1118-m (44-in.) depth for both 152-mm x 203-mm (6-in. x 8-in.) grade 2 Southern Yellow Pine timber posts and W152x13.4 (W6x9) steel posts. Five dynamic tests were conducted for each, with one of the five utilizing the extended embedment depth. The researchers noted that timber posts performed better than steel in all cases. The test results also suggested that the additional 152 mm (6 in.) of embedment depth made little difference in the stiffness or the dynamic performance of the posts. This conclusion is contradictory to most other studies concerning post embedment depth and may be attributed to the very small sample size used in the tests or other variables not considered during the testing.

Goeller et al. [22], also completed post testing in 1997 for a project studying the soil-post interaction forces during a guardrail impact. Twenty-nine post tests were conducted in soil, eleven of which were 152-mm x 203-mm (6-in. x 8-in.) wood posts, twelve of which were W6x9 steel posts, and the remainder of which were W6x16 steel posts. The results showed that the wood posts produced a lower force than the steel posts and that a triangular soil pressure distribution most closely approximated the test data.

Also in 1997, Smith et al. [23] studied the interaction of posts and guardrail. Smith concluded that the reaction of the post during vehicular collisions significantly changes depending on the soil moisture content, stating that the higher the moisture content, the lower the load capacity. Results from the ten timber tests are shown in Table 6. An impact height of 544 mm (21.4 in.) was used for all tests.

Table 6. Post Testing Matrix and Test Results Summary

Post		Soil		Peak Force	Residual Force
Length (in.)	Embedment Depth (in.)	Material	Moisture Content (%)	(kips)	(kips)
72	44	Cohesive	17.5	14	13.63
72	44	Cohesive	21.7	6.5	4.77
72	44	Cohesive	23	4.8	4.84
72	44	Cohesive	20.6	6.95	5.56
72	44	Cohesive	12.1	15	11.82
72	44	Cohesive	12.7	11	10.82
78	52	Cohesive	12.7	10.7	0
78	52	Cohesive	13.1	14	13.56
72	44	Noncohesive	2.9	9.25	5
72	44	Noncohesive	4.1	4.11	1.75

Another study of the interaction of guardrail posts and soil was conducted by Coon et al. [24]. The study examined W152x13.5 (W6x9) and W152x23.8 (W6x16) steel posts and 152-mm x 203-mm (6-in. x 8-in.) wood posts with a 549-mm (21.6-in.) impact height as well as a 1092-mm (43-in.) embedment depth. The researchers found that the energy absorbed when a wood post fractured was significantly lower than when a post rotated in the soil.

Also in 1998, Denman and Welch [25] developed the REGENT System, a flared-end terminal created to meet NCHRP Report 350 [26] Test Level 3 requirements. During their research, they noticed several problems that were attributed to the variation in the posts. For instance, in a system constructed with several Grade 2 posts followed by a Dense Select Structural post, the vehicle had a tendency to snag on the stronger post causing it to spin or rollover. After investigating the availability and the cost of stronger posts, it was decided to utilize a dual grading system, where the area 305 mm (12 in.) above and below the ground line was required to meet the select structural requirements and the remainder of the post length was allowed to fall into Grade 2.

A project completed by Kuipers and Reid [27] in 2003 studied the embedment depth for the steel posts used in the Midwest Guardrail System (MGS). In the post study, ten dynamic bogie tests were completed using standard W152x23.8 (W6x16) posts with an impact height of 630 mm (24.8 in.). W152x23.8 (W6x16) posts were used instead of the W152x13.4 (W6x9) typically used in the MGS system to avoid significant yielding of the posts during the tests, allowing researchers to focus on the influence of the soil behavior on the system.

Results from three specific tests in the study, NPGB 4, 9, and 10, are shown in Figure 1. The force from the three tests averaged about 35.1 kN (7.9 kips), with local force peaks exceeding that.

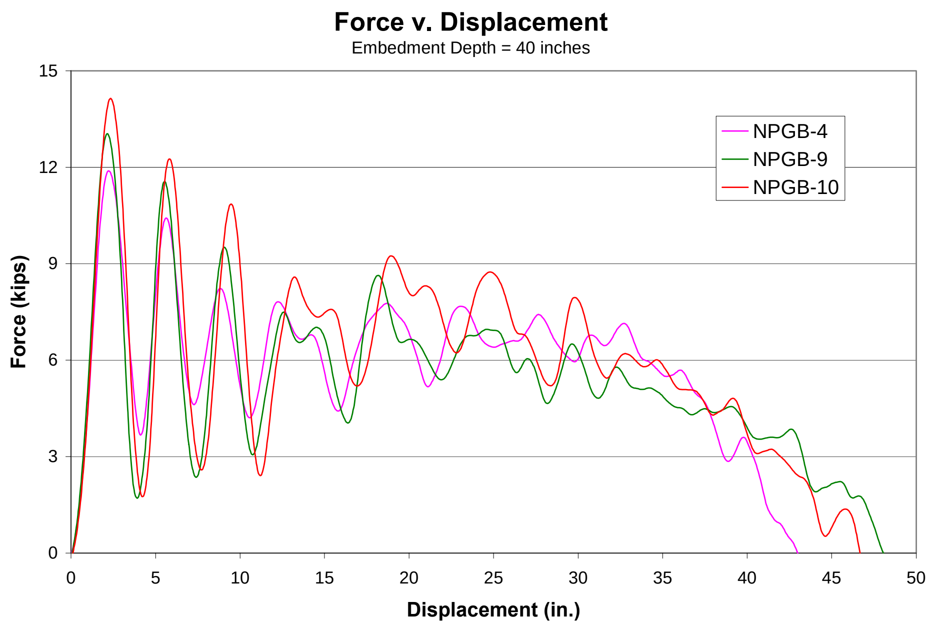


Figure 1. NPGB 4, 9, and 10 Bogie Testing Results

In the tests, it was noted that the shallow posts with a 939.8-mm (37-in.) embedment depth pulled out of the soil while the majority simply rotated in the soil. The report also showed that more energy was absorbed by the system when the posts rotated in the soil rather than being pulled out of the ground. The average energy absorbed by the rotating posts with a 1016-mm (40-in.) embedment depth was 29.8 kJ (263.8 kip-in.), while that of the posts utilizing a 940-mm (37-in.) embedment depth was only 24.9 kJ (220.4 kip-in.), resulting in a 16 percent decrease.

2.1.2 Full-Scale Crash Testing

In 1967, the federal government required that all guardrail systems pass dynamic testing. By doing so, the cost of guardrail increased by more than one dollar per foot. Bronstad [28] of SwRI and Burket of the Ohio Department of Highways looked for a way to reduce the cost. In order to verify compliance with the new regulations, six full-scale sedan crash tests were performed on several variations of the existing Ohio W-beam guardrail system. Each test examined an inexpensive modification that could be made on in-place guardrail systems, therefore avoiding the cost of replacement. Results are shown in Table 7.

Table 7. 1971 Southwest Research Institute Testing Summary

Test No.	Post Size	Weight (lbs)	Speed (mph)	Impact Angle (degrees)	Results
ODH-1	4 x 4 in.	4589	67	25	Vehicle Rolled
ODH-2	4 x 6 in.	4404	62	25.3	Good Redirection
ODH-3	7 in. diameter	4445	62.5	28.7	Vehicle Rolled
ODH-4	6 in. diameter	4242	63.1	28.3	Good Redirection (High Roll Angle)
ODH-5	6 x 6 in. Notched	4407	70.8	26.7	Good Redirection

Tests ODH 2, 4, and 5 were considered successful tests, and all three would be able to be used in roadside applications. Tests ODH 1 and 3 failed due to the vehicle rolling.

In 1988, Sicking et al. [29] conducted a study to optimize strong-post W-beam guardrail systems to lower the costs of installation and maintenance. Several full-scale sedan crash tests were completed, including tests on W-beam guardrail systems using round, 178-mm (7-in.) diameter wood posts and W152x12.6 (W6x8.5) steel posts with both 965-mm (38-in.) and 1219-mm (48-in.) embedment depths. It was found that the designs utilizing wood posts carried a much lower cost than systems using the equivalent steel counterparts. The study also found that by using an increased post spacing of 2,540 mm (100 in.) and a new 965-mm (38-in.) embedment depth, the cost for both steel and wood systems could be drastically reduced. Lastly, the report added that block-outs could be used if desired, but they were not found to be cost beneficial. The block-outs would only help to alleviate wheel snag that proved to be only a minor issue in the tests conducted.

Also in 1988, Sicking et al. [30] developed two new end treatments for the standard guardrail system that met the NCHRP 230 [31] requirements. This research effort included full-scale vehicle crash tests of a guardrail system with round, wood posts. Domed 178-mm (7-in.) diameter by 1,905-mm (75-in.) long posts were used in the system with a 965-mm (38-in.) embedment depth and a top of rail height of 686 mm (27 in.). The tests included both head-on and rail-face impacts, and proved that terminals utilizing round wood posts met impact performance guidelines.

In 1995, Bligh and Bullard [32-34] conducted a full-scale crash test of W-beam guardrail with round, Southern Pine posts. This particular test followed NCHRP Report 350 test designation 3-11, using a 2,000-kg (4409-lb) pickup truck impacting at 100 km/h (62.14 mph) and 25 degrees. The Southern Pine posts were 184 mm (7.25 in.) in diameter by 1,905 mm (75 in.) long and spaced at 1905 mm (75 in.). The embedment depth was 1,118 mm (44 in.). The blockouts were fabricated with one concave side to meet flush with the round posts. The test was successful since the vehicle was safely contained and redirected with little damage or intrusion into the occupant compartment. The researchers determined the most critical concern with the test to be the high exit angle of 26.1 degrees. However, upon review of the vehicle trajectory after leaving the rail, the possible problems derived from this high exit angle were considered to be minimal. Therefore, TTI researchers suggested that the round post system was nearly equivalent to the standard G4(2W) system and was an acceptable substitute.

In another research project, Rosson, Bierman, and Rohde [35-36] looked at methods to reduce the deflection of guardrail placed directly in front of roadside hazards. Four full-scale crash tests were conducted using steel posts, and computer simulations were used in place of four additional tests with timber posts. To complete the simulations, twenty dynamic post tests were completed, with the results presented in Table 8. The researchers found that the best option was to reduce the post spacing to half the normal spacing.

Table 8. Rosson, Bierman and Rohde Post Test Summary

Soil Type	Moisture Content	Embedment Depth	Post Type	Avgerage Force (kips)	Peak Force (kips)	Fracture Energy (kip-in.)
Clay	Low (12%)	Extended 1270 mm (50 in.)	Steel	10.76	13.45	225.96
			Timber	10.72	13.4	225.12
				13.56	16.95	284.76
		Standard 1118 mm (44 in.)	Steel	9.85	12.31	206.85
				8.55	10.69	179.55
			Timber	11.82	14.78	248.22
				10.82	13.53	227.22
	Optimum (17%)	Standard 1118 mm (44 in.)	Steel	11.29	14.11	237.09
				8.31	10.39	174.51
			Timber	13.63	17.04	286.23
				5.56	6.95	116.76
	High (25%)	Standard 1118 mm (44 in.)	Steel	4.44	5.55	93.24
				4.88	6.1	102.48
			Timber	4.77	5.96	101.64
				4.87	6.05	135.24
Sand	Unsaturated	Standard 1118 mm (44 in.)	Steel	5.97	7.16	125.37
				4.43	5.54	93.03
			Timber	6.44	8.05	135.24
				2.49	3.11	52.29

An additional project utilizing round wooden posts in a guardrail transition to concrete bridge rail was completed in 1999 by Buth et al. [37]. The Southern Pine posts used were 178 mm (7 in.) in diameter and 1905 mm (75 in.) long with a 1118-mm (44-in.) embedment depth. Once again, blockouts with a concave side were used to make a flush connection between the post and the blockout. The first test failed to meet NCHRP

Report 350 requirements, but with the insertion of two 3200 mm (126 in.) long pieces of 89 mm (3.5 in.) diameter pipe into the tubular rail element, the system proved to be adequate.

In 2004, Seckinger et al. [38-39] issued a report on a study of guardrail systems encased in pavement mow strips. In the study, steel and 178-mm (7-in.) diameter round, Southern Pine posts were tested in mow strips constructed of concrete or asphalt with various types of fill, including grout, asphalt, and rubber mats. After both bogie and full-scale testing, the recommendation was to assure a minimum 457-mm x 457-mm (18-in. x 18-in.) leave-out, or gap in the mow strip, and to fill the leave-out with a standard two-sack grout. Systems using both W152x13.4 (W6x9) steel and 178-mm (7-in.) diameter, round wood posts were successfully tested. The results showed the importance of post rotation in the success of guardrail systems. If rotation was not important, no leave-out would be required.

In summary, numerous bogie tests have been conducted on steel, rectangular wood, and round wood guardrail posts in both soil and a cantilever sleeve. Cantilever tests on round posts were conducted for Red Pine on posts with diameters ranging from 155 mm (6.1 in.) to 248 mm (9.75 in.), and led to the conclusion that for an equivalent moment of inertia, rectangular and round wood posts behaved the same.

Soil bogie tests were also conducted for a variety of posts. Round wood tests included a test on a 178 mm (7 in.) diameter SYP post embedded at 965 mm (38 in.), which showed behavior similar to steel posts embedded at 1118 mm (44 in.). Other soil tests largely concentrated on steel posts and 152-mm x 203-mm (6-in. x 8-in.) rectangular wood posts. The general trend was that the two behaved very similarly, with some tests suggesting steel posts were better and others suggesting wood posts were better. Another conclusion that was made from the testing was that increased soil moisture content lowered the capacity of the soil, and therefore the energy absorbed by a given type of post.

Full-scale crash tests were also conducted to meet NCHRP Report 230 requirements. These tests include those conducted at TTI on a standard guardrail system built with 178-mm (7-in.) diameter SYP posts embedded at both 965 mm (38 in.) and 1219 mm (48 in.). NCHRP Report 230 tests were also conducted on end treatments for the system using the same 178-mm (7-in.) diameter posts. The results suggested that utilizing round wood posts lowered the cost of the system.

Those full-scale tests meeting the requirements of NCHRP Report 350 include tests conducted on a guardrail system and a bridge rail transition section, respectively utilizing 184-mm (7.25-in.) diameter and 178-mm (7-in.) diameter SYP posts, both of which were embedded at 1118 mm (44 in.), respectively. The success of these systems formed the foundation for the work in this study.

The effects of concrete or asphalt mow strips were also investigated under NCHRP Report 350 for a system using 178-mm (7-in.) diameter SYP posts. The findings specified a minimum leave out section of 457-mm x 457-mm (18-in. x 18-in.).

2.2 Grading

In the United States, six associations are responsible for establishing and publishing grading rules. Since this study was limited to the Douglas Fir and Ponderosa Pine species, only two were determined to be applicable, the Western Wood Products Association (WWPA) [40] and the West Coast Lumber Inspection Bureau [41].

Although not an exact science, grading lumber is a means of separating the lumber by its quality, strength, and appearance. One set of grading rules, published by the WWPA, pertains to the Ponderosa Pine and Douglas Fir species. These rules separate timber into eight categories, Select Structural, No. 1, No. 2, and No. 3, and four corresponding dense categories. Dense grades follow the same guidelines as the other four categories, but have 6 or more annual rings per inch with 1/3 or more of the ring being summerwood. The grading criteria are listed in Table 9. Lumber can also be categorized as dense if at least 1/2 of the material is summerwood.

Table 9. WWPA Timber Grading Summary

Defect	Select Structural	No. 1	No. 2	No. 3
Checks	Seasoning checks - single or opposite with sum less than half the thickness of a piece	Seasoning checks - single or opposite with sum less than half the thickness of a piece	Seasoning Checks	Seasoning Checks
Pockets	Medium Pitch Pockets	Medium Pitch Pockets	Pitch or Bark Pockets	Pitch or Bark Pockets
Slope of Grain	1 in 12	1 in 10	1 in 6	No Limit
Shakes	1/3 Thickness on end	1/3 Thickness on end	1/2 length, 1/2 thickness, limited as splits if through ends	Full length if not continuous
Splits	Equal in length to 3/4 thickness of the piece or equivalent end checks	Equal in length to width of the piece or equivalent end checks	Medium or equivalent end checks	1/4 length
Wane	1/8 width of any face or equivalent slightly more for short distances	1/4 width of any face or equivalent slightly more for short distances	1/3 width of any face or equivalent slightly more for short distances	1/3 width of any face or equivalent slightly more for short distances
Skips	Occasional 1/16 in deep, 2' long	Occasional 1/8 in deep, 2' long	1/8" deep, 2' long, 1/16" deep if full length	1/8" in both width and thickness if surfaced, 1/2" scant if rough
Knots	As Per Table 13			

The WWPA rules contain many different criteria for knots depending on the grade. Table 10 shows the acceptable knot sizes for the top three grades. Knots for Grade No. 3 are simply limited to ¾ the width of the face on which the knot is found. In the WWPA rules, the knot size permitted on the widest face is permitted on all faces.

Table 10. WWPA Knot Grading Criteria

Wide Face Width	Knot Size Permitted		
	Select Structural Timbers	Grade No. 1	Grade No. 2
5"	1”	1-1/2”	2-1/4”
6"	1-1/4”	1-7/8”	2-3/4”
8"	1-5/8”	2-1/2”	3-3/4”
10"	2”	3-1/8”	4-3/4”
12"	2-3/8”	3-3/4”	5-3/4”
14"	2-1/2”	4”	6-3/4”
16"	2-3/4”	4-1/4”	7-3/4”
18"	3”	4-1/2”	8-3/4”

The second set of grading rules is Standard No. 17, written by the West Coast Lumber Inspection Bureau (WCLB). This standard pertains to the Douglas Fir species and specifies grading rules identical to those of the WWPA with two exceptions. First, Standard No. 17 does not separate mining grades from post and timber grades as the WWPA does. Second, there is no No. 3 grading category. Since, mining grades are not assigned stress values, they will not be relevant to the study. The relevant WCLB grades are Select Structural, No. 1 Structural, and No. 2 Structural. These grades are exactly equivalent to WWPA grades Select Structural, No.1, and No. 2, respectively.

3 SAMPLING

3.1 Sample Collection

Initially, a post diameter was selected for the two species based on the success of 184-mm (7.25-in.) diameter Southern Pine guardrail posts in the full-scale crash tests conducted by Bligh and Bullard [32-34] in 1995. Sizes were determined based on tabulated Douglas Fir and Ponderosa Pine strength values to carry a bending moment equivalent to that of the Southern Pine posts. These sizes were 216 mm (8.5 in.) for Ponderosa Pine and 191 mm (7.5 in.) for Douglas Fir as shown in Figure 2. The 1981-mm (78-in.) length was arbitrarily selected to assure enough length to increase the post embedment depth if needed.

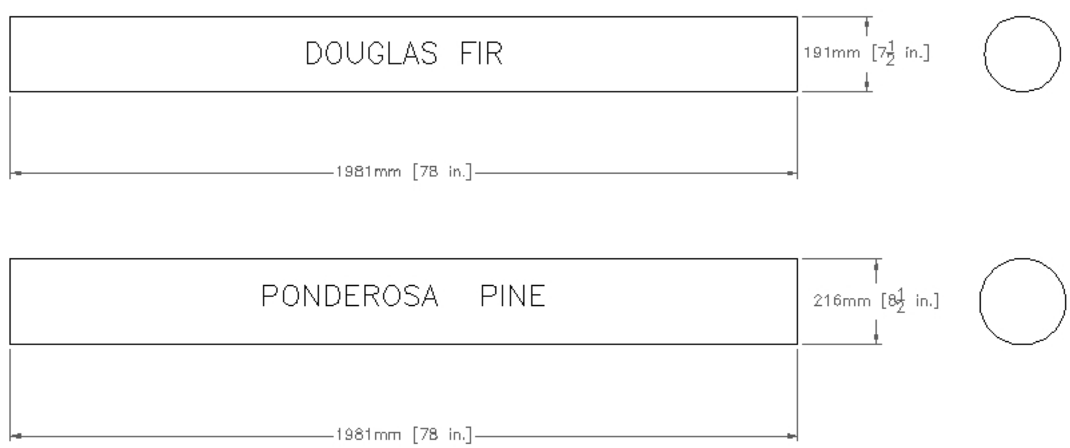


Figure 2. Major Dimensions of Round Wood Posts

Unlike some materials, wood is highly variable. Its strength can drastically change with variation in species, ring density, knot size and density, moisture content, and even region of origin. Ponderosa Pine is simply not as strong as Douglas Fir, and both are typically weaker than Southern Yellow Pine.

Attempting to investigate the effects of the two most influential variables, knots and ring density, three categories of posts were defined. The categories were low ring density without knots (BASELINE), low ring density with knots (KNOTS), and high ring density without knots (HRD). Posts were categorized based on ring density, knot frequency, and knot density. Posts with 4 or fewer rings-per-inch were defined as low ring density and 6 or more rings-per-inch were defined as high rings density. Posts with any knots larger than 63.5 mm (2.5 in.) in diameter were placed in the knots category, while posts with knots that were less than 38.1 mm (1.5 in.) in diameter were considered to be without knots and could be placed in the baseline or HRD categories. A portion of the testing was intended to isolate the properties of posts in these three categories and a portion was intended to determine the properties of the random population.

Categorized posts were selected first to assure that each category had a sample of 10 posts. When those 30 posts were selected, another 40 posts were randomly pulled from the production line to establish a random population sample for static testing. Ponderosa Pine samples were donated by Hill Products Group, and Douglas Fir samples were donated by All-Weather Wood Products.

When the sample arrived at the test site, researchers estimated the Modulus of Elasticity (MOE) for each post using a stress wave technique [42]. Using this technique, each post was tapped once with a hammer, sending a stress wave through the post. At the same time, a sensor determined the time the stress wave took to travel to the other end of the post and return. Knowing this time and the length of the post, the wave velocity could be calculated and used with the mass density to determine the MOE. Posts were then ranked within each category by the estimated MOE values. Once the order was determined, the posts were paired in order, making a total of five pairs per category. With both posts in a pair having similar MOE values, one was randomly chosen to be sent to the Forest Products Lab for static testing and the other remained in Lincoln for dynamic testing.

3.2 Sample Documentation

The posts were extensively documented. Moisture contents were measured at three locations: 533 mm (21 in.), 991 mm (39 in.), and 1448 mm (57 in.) from the bottom of the post using a pin-type moisture meter. The area within this region was defined as the critical zone, the zone where fracture was likely to occur. Circumference was also measured in the three locations of the critical zone and additionally at both the top and bottom of the post. Weights and lengths were measured to determine an approximate density. Ring counts were taken over a three-inch length, and knots were carefully documented. Photographs of each post were also taken during documentation.

To record the knots on the round posts, a unique procedure had to be adopted. A circular template with a radial mark at every 5th degree, similar to a protractor, was created to sit on top of the post. An arrow was randomly drawn on the top of the posts, defining the front of each post, and the zero-degree mark was aligned with the arrow. Each knot was given an angle and a distance from the top of the post down to the center of the knot. Additionally, dimensions were recorded for the size of each knot. The same procedure was used for gouges and other defects in the posts. Summaries of the documentation are presented in Table 11 and Table 12. Tables containing all of the post properties are presented in Appendix A.

Table 11. Ponderosa Pine Pre-test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume (in.^{3})	Density (lb/in.^{3})	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Ponderosa Pine	101	77	77.979	25.958	26.125	26.000	4191	0.0184	20	19	19	6.00
	104	119.5	78.042	28.250	27.750	28.125	4923	0.0243	22	19	23	5.67
	105	115	78.042	27.708	27.375	27.500	4742	0.0243	19	16	26	7.33
	106	73	77.875	27.917	28.125	27.375	4822	0.0151	32,21	33,19	29,18	5.67
	109	81	78.000	26.333	25.625	28.125	4355	0.0186	20	18	17	5.00
	111	105	78.000	27.792	27.750	27.750	4790	0.0219	19	19	22	14.00
	112	112	78.000	28.083	27.000	28.125	4847	0.0231	23	19	19	25.00
	117	77	78.083	27.917	27.625	27.500	4805	0.0160	20	22	18	18.33
	118	102	77.938	28.125	27.500	28.000	4875	0.0209	19	20	19	9.33
	120	128	78.021	27.708	27.500	27.750	4758	0.0269	20	19	22	12.67
	122	110	78.063	28.417	30.375	27.750	5078	0.0217	21	19	23	11.00
	123	75	78.000	25.333	27.125	26.250	4104	0.0183	23	20	16	11.67
	124	99	78.042	27.833	27.875	28.250	4832	0.0205	22	23	19	16.67
	127	116	78.021	27.750	27.500	28.000	4781	0.0243	25	22	28	13.00
	128	83	78.000	25.833	27.375	25.375	4192	0.0198	16	15	16	10.67

Table 12. Douglas Fir Pre-test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume ($in.^3$)	Density ($lb/in.^3$)	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Douglas Fir	2	55	78.250	23.083	22.625	23.500	3308	0.0166	30	25	43	9.67
	3	63	77.958	22.542	22.875	22.750	3175	0.0198	51,26	45,28	54,30	25.67
	6	58	77.083	22.958	23.000	22.375	3252	0.0178	23	22	24	8.00
	9	59	78.000	22.917	22.625	23.375	3267	0.0181	26	26	24	14.33
	10	60	78.042	23.042	22.500	22.750	3264	0.0184	21	20	31	7.00
	11	55	78.042	23.083	22.625	23.000	3287	0.0167	22	33	22	19.33
	13	62	77.521	22.958	22.750	23.000	3267	0.0190	43	30	51	8.33
	15	71	78.000	22.833	22.875	23.125	3249	0.0219	45	39	50	11.00
	18	50	78.000	22.667	22.250	22.375	3163	0.0158	27	26	31	10.00
	20	56	78.000	22.833	22.750	22.875	3236	0.0173	21	23	25	13.00
	22	46	77.917	23.208	23.500	23.000	3348	0.0137	30	26	32	5.33
	24	63	77.438	22.542	23.125	22.500	3177	0.0198	34	28	32	5.33
	25	63	77.750	23.583	23.500	23.500	3447	0.0183	50	53	45	7.33
	26	56	77.375	23.000	23.000	22.250	3256	0.0172	55	27	48	6.33
	27	49	77.500	23.125	23.125	22.875	3310	0.0148	22	30	25	6.00

As the moisture content of a wood post increases up to 23 percent, the strength of the wood fibers within the post decreases. Beyond 23 percent, the wood strength is fairly constant. In their actual use, the moisture content may exceed 23 percent, and therefore the posts would be saturated. Upon completion of documentation, the posts were placed in a 1219-mm (48-in.) deep tank of water in an effort to saturate the critical zone of the posts, replicating the worst case scenario the posts may when used in a guardrail system.

The moisture content and weight of the posts were measured again on test day to give a more accurate representation of the posts after they had been soaked in water. The results of those measurements are shown in Table 13 and Table 14. Note that all of the posts were saturated in the critical region.

Table 13. Douglas Fir Test Day Measurements

Test No.	Post No.	Weight (lbs)	Moisture Content (%)			Circumference at Bottom (in.)
			21 in. from Top	Mid-Length	21 in. from Bottom	
DF-1	2	76	10	37	59	23 5/8
DF-2	3	76	16	40	56	22 7/8
DF-3	6	64	16	50	65	22 3/4
DF-4	9	64	15	30	64	23 1/2
DF-5	10	67	16	67	64	23
DF-6	11	74	15	41	63	23 1/4
DF-7	13	73	17	62	59	23 1/8
DF-8	15	82	16	55	59	23 3/8
DF-9	18	70	18	31	61	23
DF-10	20	73	15	51	57	23 1/4
DF-11	22	61	24	29	37	23 1/4
DF-12	24	61	17	28	31	22 3/4
DF-13	25	75	40	31	32	23 5/8
DF-14	26	68	18	26	45	22 1/2
DF-15	27	64	22	51	61	23 1/2

Table 14. Ponderosa Pine Test Day Measurements

Test No.	Post No.	Weight (lbs)	Moisture Content (%)			Circumference at Bottom (in.)
			21 in. from Top	Mid-Length	21 in. from Bottom	
PP-1	101	113	17	39	43	26
PP-2	104	130	16	27	26	28
PP-3	105	131	16	28	31	27 1/2
PP-4	106	97	15	39	38	27 1/2
PP-5	109	90	13	18	38	29 1/4
PP-6	111	120	15	35	38	28 3/4
PP-7	112	128	19	26	27	29 1/4
PP-8	117	101	15	33	38	28 3/4
PP-9	118	112	15	23	36	28
PP-10	120	130	17	29	30	28
PP-11	122	149	19	51	49	27 3/4
PP-12	123	103	31	48	41	27 1/4
PP-13	124	133	17	43	52	29 3/8
PP-14	127	125	21	32	36	28
PP-15	128	93	26	42	47	25 1/2

4 PHYSICAL TESTING - ROUND ONE

4.1 Purpose

In previous research, there has been no dynamic testing of round Ponderosa Pine or Douglas Fir posts, and therefore bogie tests were undertaken on both species to determine their dynamic properties.

4.2 Scope

Initial bogie tests were conducted with the round posts installed in a rigid steel sleeve embedded in concrete. Fifteen tests were conducted for both species. The target impact condition for the tests was 32 km/h (20 mph), with the impact occurring at the centerline of the bogie, 632 mm (24.875 in.) above the ground. The angle of impact was irrelevant since a round cross-section does not have a strong or weak axis. Therefore, the arrow randomly drawn on the top of the post during documentation was used as the impact side. The testing matrix for the thirty initial tests is shown in Figure 3 below, and the test setup and impact conditions are shown in Figure 4.

Test No.	Post No.	Wooden Post Type	Post Length (in.)	Post Diameter (in.)
DF-1	2	Douglas Fir	78.3	7.35
DF-2	3	Douglas Fir	78.0	7.18
DF-3	6	Douglas Fir	77.1	7.31
DF-4	9	Douglas Fir	78.0	7.29
DF-5	10	Douglas Fir	78.0	7.33
DF-6	11	Douglas Fir	78.0	7.35
DF-7	13	Douglas Fir	77.5	7.31
DF-8	15	Douglas Fir	78.0	7.27
DF-9	18	Douglas Fir	78.0	7.22
DF-10	20	Douglas Fir	78.0	7.27
DF-11	22	Douglas Fir	77.9	7.39
DF-12	24	Douglas Fir	77.4	7.18
DF-13	25	Douglas Fir	77.8	7.51
DF-14	26	Douglas Fir	77.4	7.32
DF-15	27	Douglas Fir	77.5	7.36
PP-1	101	Ponderosa Pine	78.0	8.26
PP-2	104	Ponderosa Pine	78.0	8.99
PP-3	105	Ponderosa Pine	78.0	8.82
PP-4	106	Ponderosa Pine	77.9	8.89
PP-5	109	Ponderosa Pine	78.0	8.38
PP-6	111	Ponderosa Pine	78.0	8.85
PP-7	112	Ponderosa Pine	78.0	8.94
PP-8	117	Ponderosa Pine	78.1	8.89
PP-9	118	Ponderosa Pine	77.9	8.95
PP-10	120	Ponderosa Pine	78.0	8.82
PP-11	122	Ponderosa Pine	78.1	9.05
PP-12	123	Ponderosa Pine	78.0	8.06
PP-13	124	Ponderosa Pine	78.0	8.86
PP-14	127	Ponderosa Pine	78.0	8.83
PP-15	128	Ponderosa Pine	78.0	8.22

NOTES:

(1) TARGET SPEED = 20 MPH

(2) IMPACT ORIENTATION: CENTERLINE OF POST (W/ARROW POINTING TOWARD BOGIE) AND CENTERLINE OF BOGIE

Midwest Roadside Safety Facility

FOREST PRODUCTS LAB
ROUND POST TESTING
BOGIE SETUP
TEST MATRIX

Sheet: 4 of 4
Date: 11/2/04
By: JAH
Drawing Name: FPL Bogie Testing Matrix
Scale: None
Rev: KAP

Figure 3. Bogie Testing Matrix

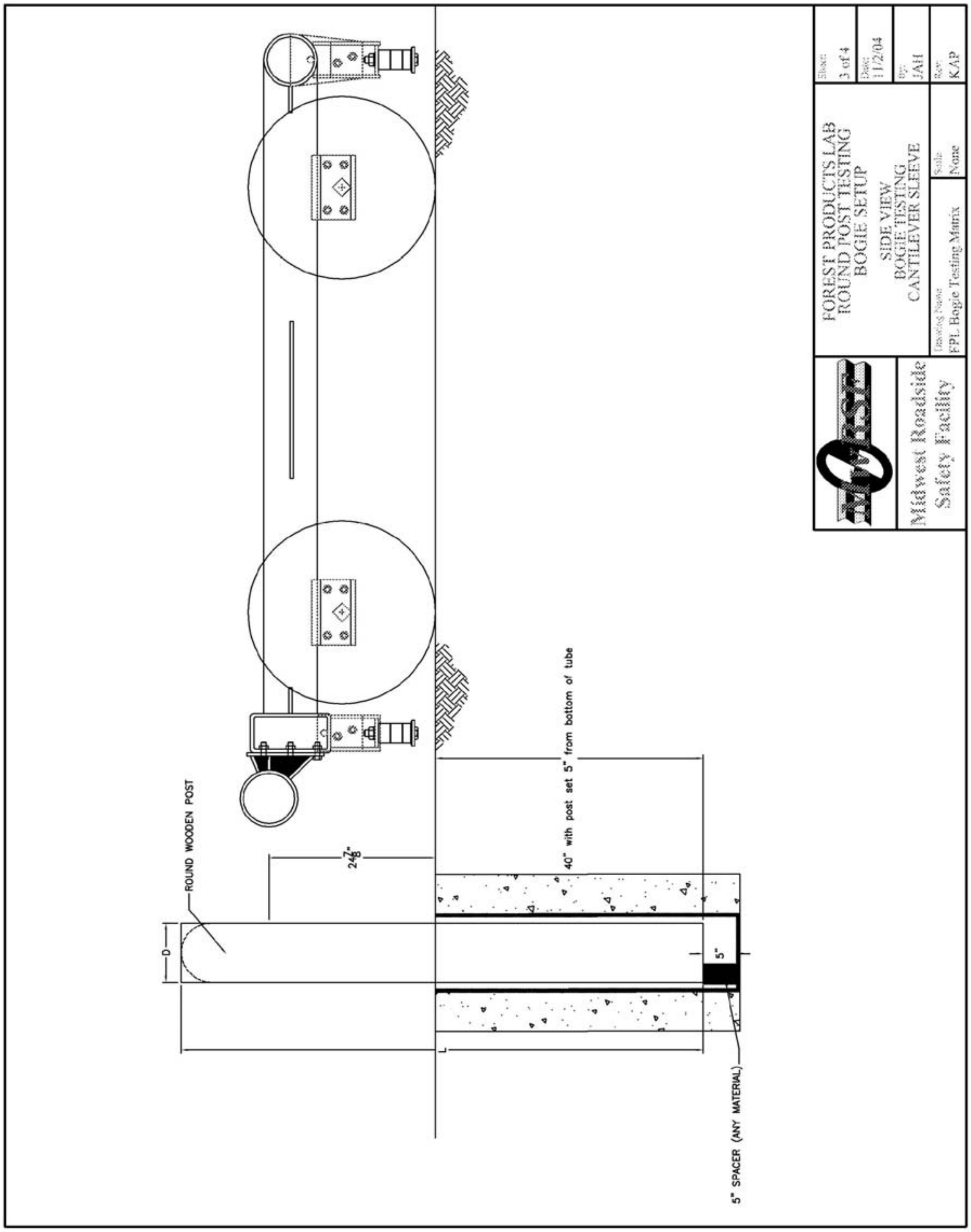


Figure 4. Bogie Testing Setup

4.3 Round Wood Post

Compared to steel sections, wood posts have highly variable sizes. Although two posts may have the same nominal diameter, it is not likely that the actual diameters will be the same. Because of this, it is incorrect to compare the resistive moments or resistive forces of the posts directly. Instead, a factor must be introduced that allows comparisons to be made between posts with different sizes. This factor is the Modulus of Rupture.

The Modulus of Rupture (MOR) is the maximum stress felt in the outer fibers of the post. The MOR is calculated by dividing the maximum bogie impact moment, M_{MAX}, by the section modulus, S, of the post. Because it is a stress value, the cross-section and the applied moment have already been taken into account, making it possible to compare post strengths without consideration of the cross-section or loading condition.

$$MOR = \frac{M_{MAX}}{S} \qquad S = \frac{(\pi)(r)^3}{4}$$

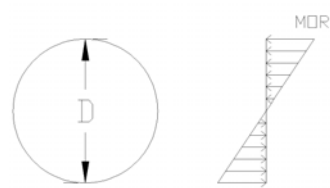


Figure 5. Bending Stress Distribution

4.4 Equipment and Instrumentation

A variety of equipment and instrumentation was used to record and collect data. It was 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 Cameras
- Digital Video Cameras

4.4.1 Bogie

A rigid-frame bogie was used to impact the posts. A variable height, detachable impact head was constructed and used in the testing. The bogie head was constructed of 203-mm (8-in.) diameter, 12.5-mm (0.5-in.) thick standard steel pipe, with 19-mm (0.75-in.) neoprene belting wrapped around the pipe to prevent local damage to the post from the impact. The impact head was bolted to the bogie vehicle, creating a rigid frame. The bogie with the impact head is shown on the guidance track in Figure 6. Use of this impact head allowed a 632-mm (24.875-in.) impact height, corresponding to the MGS mounting height. The weight of the bogie with the addition of the mountable impact head was 728 kg (1605 lbs). The speed chosen for the first set of impact tests, 32 km/h (20 mph), approximated the lateral velocity of the posts in a full scale system impact.

A pickup truck with a reverse cable tow system was used to propel the bogie. When the bogie reached the end of the guidance system, it was released from the tow cable, allowing it to be free rolling when it impacted the post. A remote braking system was installed on the bogie allowing it to be safely brought to rest after the test.

Figure 6. Rigid Frame Bogie on Guidance Track

4.4.2 Accelerometer

One triaxial piezoresistive accelerometer system with a range of ±200 G's was mounted on the bogie vehicle near its center of gravity, and used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The accelerometer, Model EDR-3, was developed by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", were used to analyze and plot the accelerometer data.

4.4.3 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. The system recorded the signals and the time each occurred. The speed was then calculated using the spacing between the sensors and the time between the signals.

4.4.4 Photography Cameras

One high-speed Photron digital video camera or one high-speed VITcam digital video camera, both with speeds of 500 frames per second, was used to document each test. One Canon digital video camera with a speed of 29.97 frames per second was also employed to document each test. Both cameras were placed approximately 25 ft from the centerline of the posts, with a field of view perpendicular to the bogie's direction of travel. Flood lights were used to light the base of the posts, allowing the fracture and fracture surface to be clearly examined in the videos. A Nikon Coolpix 8700 digital camera was used to document pre- and post-test conditions of each post.

4.5 Data Processing

Initially, the data was filtered using a SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [43-44]. 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 velocity throughout the test. The calculated bogie's velocity trace was then integrated to find the displacement. Subsequently, the force-deflection curve was plotted for each test. Finally, integration of the force-deflection curve provided the energy-displacement curve for each test.

4.6 End of Test Determination

During an impact, the accelerometer records the accelerations the bogie feels from all sources, not just the post. Because of this, vibrations in the bogie vehicle, impact head, and accelerometer mounting assembly are also recorded and result in a high frequency acceleration trace. Since the bogie vehicle may still be vibrating after the impact event, the data may extend well beyond the failure of the post. For this reason, the end of the test needed to be defined in some manner.

In general, this event time was identified as the third time the filtered acceleration trace crossed the X-axis from positive to negative. However, in many cases this resulted in unreasonably long test durations, so two limits were established. First, all tests were limited to a 20 in. maximum deflection because it was decided that no post would have the capacity to deflect more than 508 mm (20 in.) in a cantilever sleeve without complete fracture. Second, each test was limited by the bogie-post contact time. For each test, the high-speed video was used to establish the length of time the bogie was actually in contact with the post. This time was then used to define the end of the test.

5 ROUND 1 CANTILEVER TEST RESULTS

5.1 Introduction

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 B. A summary of all of the round one tests is provided in Table 15 for the Ponderosa Pine species and Table 16 for the Douglas Fir species.

5.2 MOR Results

The MOR was calculated for each test and is shown in the mentioned tables. Douglas Fir resulted in the highest average MOR value of 59.4 MPa (8.6 ksi), and Ponderosa Pine resulted in an average MOR value of 49.0 MPa (7.1 ksi). As expected due to the dynamic nature of the testing and the benefits of the round cross-section, both MOR averages were higher than the tabulated values of 52 MPa (7.5 ksi) for Douglas Fir and 35 MPa (5.1 ksi) for Ponderosa Pine found in the Wood Handbook [45].

5.2.1 Ponderosa Pine

The 48.0 MPa (7.1 ksi) average MOR for Ponderosa Pine can also be broken down into three categories. The baseline category, low ring density without knots, showed the lowest MOR with a value of 39.0 MPa (5.66 ksi). The high ring density category showed the highest MOR with a value of 63.3 MPa (9.18 ksi), while the knots category fell in between with an MOR of 44.8 MPa (6.50 ksi). Although the results may seem alarming since the knots category fell above the baseline category, special attention should be given to the ring density of the posts within the knots category as it was, on average, more than twice as high as the ring density of the posts within the baseline category. This is likely the reason the knots category was stronger than the baseline category.

5.2.2 Douglas Fir

Similar to Ponderosa Pine, the baseline category also ranked lowest for the Douglas Fir tests with an average MOR of 51.7 MPa (7.50 ksi). Next highest was the knots category at 60.9 MPa (8.83 ksi). Highest for the species, the HRD average MOR was 65.5 MPa (9.50 ksi). The difference between the highest and lowest categories was more than 25 percent, a significant variation for posts of the same species from the same region. Once again, the average ring density for the knots category was more than twice that of the baseline category, likely resulting in a large influence on strength.

These results demonstrate that there may be some correlation between the presence of knots and a higher ring density. The random sample, however, does not strongly support this, since posts with small knots also have a high ring density. Instead, it suggests that the average ring density for the baseline category was abnormally low. For Ponderosa Pine, the average ring density for the baseline category was 5.9 rings-per-inch, while the random population average was 11.6 rings-per-inch. The same is true for Douglas Fir in which case the average ring density for the baseline category was 6.1 rings-per-inch, and the random population average was 10 rings-per-inch.

5.3 Force Results

As stated previously, the guardrail posts must have sufficient strength to overcome the soil resisting moment. This means that the peak force a post is able to resist is a key factor in determining its acceptability.

5.3.1 Ponderosa Pine

For the Ponderosa Pine species, the average peak force was 83.6 kN (18.8 kips) with a standard deviation of 28.8 kN (6.5 kips). The maximum force from this set of tests was 144.3 kN (32.4 kips) and was from test PP-7, a HRD post. The minimum force was 56.8 kN (12.8 kips). The highest average force for a category was 112.9 kN (25.4 kips) for the HRD category. The knots category was next with 73.3 kN (16.5 kips). Finally, the baseline category showed the lowest average force at 64.7 kN (14.5 kips).

5.3.2 Douglas Fir

The second species had a lower average peak force value of 58.7 kN (13.2 kips), but also had a much smaller diameter. From the MOR data, if posts of the two species would have been the same size, the Douglas Fir posts would have had the higher peak force capacity.

The standard deviation for the tests was 13.2 kN (2.8 kips). The post with the highest peak load was DF-2 from the HRD category with a peak of 83.5 kN (18.8 kips). The lowest force value was 39.8 kN (9.0 kips) recorded from test DF-11 which was one of the five baseline tests. The averages for individual categories were 64.4 kN (14.5 kips) for the HRD category, 59.7 kN (13.4 kips) for the knots category, and 51.0 kN (11.7 kips) for the baseline category.

Table 15. Dynamic Ponderosa Pine Round Wood Post Test Results

	Post Test No.	Post No.	Category	Ring Density	Average Diameter		Peak Force Time	Peak Force Force		Peak Force Deflection		Peak Force Energy		Rupture Time	Rupture Deflection		Rupture Energy		Moisture Content	Modulus of Rupture		Impact Velocity	
				rings/in.	mm	(in.)	ms	kN	(kips)	mm	(in.)	kJ	(kip-in.)	ms	mm	(in.)	kJ	(kip-in.)	(%)	Mpa	(k/in.^{2})	m/s	(mph)
Ponderosa Pine	PP-1	101	BASELINE	6.00	210	(8.3)	5.3	57.1	(12.8)	49	(1.9)	1.24	(10.9)	46.6	410	(16.2)	3.80	(33.7)	43	39.8	(5.77)	9.2	(20.6)
	PP-2	104	BASELINE	5.67	228	(9.0)	5.6	66.5	(15.0)	50	(2.0)	1.51	(13.3)	60.6	509	(19.9)	4.65	(41.1)	26	35.9	(5.21)	8.9	(20.0)
	PP-3	105	BASELINE	7.33	224	(8.8)	5.6	75.1	(16.9)	50	(2.0)	1.76	(15.6)	15.3	132	(5.2)	5.11	(45.3)	31	43.0	(6.24)	9.0	(20.2)
	PP-4	106	BASELINE	5.67	226	(8.9)	5.3	61.5	(13.8)	49	(1.9)	1.42	(12.6)	35	317	(12.5)	2.59	(22.9)	38	34.4	(4.99)	9.4	(21.0)
	PP-5	109	BASELINE	5.00	213	(8.4)	12.2	63.2	(14.2)	108	(4.3)	3.26	(28.9)	53.1	451	(17.7)	5.26	(46.6)	38	42.1	(6.11)	9.1	(20.4)
	BASELINE Average			5.93	220	(8.7)	6.8	64.7	(14.5)	61	(2.4)	1.84	(16.3)	42.12	364	(14.3)	4.28	(37.9)	35	39.0	(5.66)	9.1	(20.4)
	PP-11	122	KNOTS	11.00	230	(9.0)	6.6	83.4	(18.8)	61	(2.4)	1.98	(17.6)	16.3	145	(5.7)	5.56	(49.2)	49	44.3	(6.42)	9.3	(20.9)
	PP-12	123	KNOTS	11.67	205	(8.1)	5.6	56.8	(12.8)	52	(2.0)	1.32	(11.7)	45.9	410	(16.1)	3.10	(27.5)	41	42.5	(6.17)	9.3	(20.8)
	PP-13	124	KNOTS	16.67	225	(8.9)	5.9	70.7	(15.9)	54	(2.1)	1.63	(14.4)	12.2	109	(4.3)	3.46	(30.7)	52	39.9	(5.79)	9.2	(20.5)
	PP-14	127	KNOTS	13.00	224	(8.8)	13.1	92.9	(20.9)	115	(4.5)	4.89	(43.3)	16.3	141	(5.5)	6.53	(57.8)	36	52.9	(7.68)	9.1	(20.3)
	PP-15	128	KNOTS	12.67	209	(8.2)	5.3	62.9	(14.1)	46	(1.8)	1.27	(11.3)	24.1	199	(7.8)	4.14	(36.7)	47	44.4	(6.44)	8.7	(19.5)
	KNOTS Average			13.00	218	(8.6)	7.3	73.3	(16.5)	66	(2.6)	2.22	(19.6)	22.96	201	(7.9)	4.56	(40.4)	45	44.8	(6.50)	9.1	(20.4)
	PP-6	111	HRD	14.00	225	(8.8)	12.5	137.0	(30.8)	114	(4.5)	6.23	(55.1)	53.4	438	(17.2)	10.32	(91.4)	38	77.7	(11.28)	9.4	(21.1)
	PP-7	112	HRD	25.00	227	(8.9)	12.5	144.3	(32.4)	111	(4.4)	6.33	(56.0)	67.5	507	(20.0)	14.26	(126.2)	27	79.3	(11.51)	9.2	(20.7)
	PP-8	117	HRD	18.33	226	(8.9)	12.2	96.7	(21.7)	111	(4.4)	4.72	(41.8)	16.6	147	(5.8)	6.58	(58.3)	38	54.1	(7.85)	9.3	(20.9)
	PP-9	118	HRD	9.33	227	(9.0)	5.6	67.8	(15.2)	52	(2.0)	1.52	(13.4)	35.6	314	(12.3)	4.37	(38.6)	36	37.1	(5.38)	9.3	(20.8)
	PP-10	120	HRD	12.67	224	(8.8)	11.6	118.9	(26.7)	101	(4.0)	5.41	(47.9)	65.6	508	(20.0)	9.81	(86.8)	30	68.1	(9.87)	9.0	(20.2)
	HRD Average			15.87	226	(8.9)	10.88	112.9	(25.4)	98	(3.8)	4.84	(42.8)	47.74	383	(15.1)	9.07	(80.3)	34	63.3	(9.18)	9.3	(20.7)
	Avg.			**11.60**	**221**	**(8.7)**	**8.326667**	**83.6**	**(18.8)**	**75**	**(2.9)**	**2.97**	**(26.2)**	**37.6**	**316**	**(12.4)**	**5.97**	**(52.8)**	**38**	**49.04**	**(7.1)**	**9.2**	**(20.5)**
	St. Dev.			**5.54**	**8.04**	**(0.3)**	**3.427091**	**28.8**	**(6.5)**	**30**	**(1.2)**	**1.97**	**(17.4)**	**19.9**	**156**	**(6.1)**	**3.19**	**(28.3)**	**8**	**14.67**	**(2.1)**	**0.2**	**(0.4)**

***Data Filtered According to SAE J211/1 Requirements**

(green) Limited by Maximum Deflection Criterion (20 in.)

(yellow) Limited by Time of Contact

Table 16. Dynamic Douglas Fir Round Wood Post Test Results

	Post Test No.	Post No.	Category	Ring Density	Average Diameter		Peak Force							Rupture						Moisture Content	Modulus of Rupture		Impact Velocity	
							Time	Force		Deflection		Energy		Time	Deflection		Energy						
				rings/in.	mm	(in.)	ms	kN	(kips)	mm	(in.)	kJ	(kip-in.)	ms	mm	(in.)	kJ	(kip-in.)	(%)	Mpa	(k/in.^{2})	m/s	(mph)
Douglas Fir	DF-11	22	BASELINE	5.33	187	(7.4)	5	39.8	(9.0)	45	(1.8)	0.88	(7.8)	40.6	359	(14.1)	2.69	(23.8)	37	38.8	(5.63)	9.1	(20.4)
	DF-12	24	BASELINE	5.33	182	(7.2)	12.5	65.1	(14.6)	113	(4.5)	3.04	(26.9)	28.8	254	(10.0)	3.67	(32.5)	31	69.2	(10.04)	9.2	(20.7)
	DF-13	25	BASELINE	7.33	191	(7.5)	5.6	56.6	(12.7)	52	(2.0)	1.29	(11.4)	36.9	326	(12.8)	3.74	(33.1)	32	52.6	(7.62)	9.2	(20.7)
	DF-14	26	BASELINE	6.33	186	(7.3)	11.9	47.1	(10.6)	106	(4.2)	2.81	(24.8)	60.6	506	(19.9)	6.76	(59.8)	45	47.2	(6.84)	9.1	(20.3)
	DF-15	27	BASELINE	6.00	187	(7.4)	11.6	51.5	(11.6)	105	(4.1)	2.75	(24.3)	37.2	326	(12.9)	4.63	(41.0)	61	50.7	(7.36)	9.2	(20.6)
	BASELINE Average			6.07	187	(7.4)	9.32	52.0	(11.7)	84	(3.3)	2.15	(19.1)	40.82	354	(13.9)	4.30	(38.0)	41	51.7	(7.50)	9.2	(20.5)
	DF-6	11	KNOTS	19.33	186	(7.3)	11.9	53.8	(12.1)	108	(4.3)	3.24	(28.7)	50.9	446	(17.5)	5.24	(46.4)	63	53.3	(7.73)	9.3	(20.9)
	DF-7	13	KNOTS	8.33	185	(7.3)	5.3	44.1	(9.9)	47	(1.9)	0.94	(8.3)	20.3	177	(7.0)	2.50	(22.1)	59	44.4	(6.44)	9.0	(20.1)
	DF-8	15	KNOTS	11.00	184	(7.3)	11.9	76.9	(17.3)	100	(3.9)	3.39	(30.0)	64.7	506	(19.9)	6.58	(58.2)	59	78.7	(11.42)	8.6	(19.3)
	DF-9	18	KNOTS	10.00	183	(7.2)	12.5	68.0	(15.3)	110	(4.3)	3.27	(28.9)	40.6	345	(13.6)	5.08	(45.0)	61	71.1	(10.32)	9.0	(20.2)
	DF-10	20	KNOTS	13.00	184	(7.3)	12.5	55.7	(12.5)	113	(4.4)	3.24	(28.7)	39.7	348	(13.7)	4.02	(35.6)	57	57.0	(8.26)	9.2	(20.7)
	KNOTS Average			12.33	185	(7.3)	10.82	59.7	(13.4)	96	(3.8)	2.82	(24.9)	43.24	364	(14.3)	4.68	(41.5)	60	60.9	(8.83)	9.0	(20.2)
	DF-1	2	HRD	9.67	186	(7.3)	11.9	73.1	(16.4)	107	(4.2)	3.39	(30.0)	45.9	392	(15.4)	5.86	(51.9)	59	72.4	(10.50)	9.2	(20.5)
	DF-2	3	HRD	25.67	182	(7.2)	12.5	83.5	(18.8)	112	(4.4)	3.78	(33.5)	62.5	508	(20.0)	8.64	(76.5)	56	88.7	(12.87)	9.1	(20.4)
	DF-3	6	HRD	8.00	185	(7.3)	12.2	60.0	(13.5)	110	(4.3)	2.89	(25.6)	39.7	345	(13.6)	4.44	(39.3)	65	60.3	(8.75)	9.2	(20.5)
	DF-4	9	HRD	14.33	185	(7.3)	12.5	60.0	(13.5)	105	(4.1)	2.71	(24.0)	63.4	504	(19.8)	4.87	(43.1)	64	60.7	(8.81)	8.6	(19.2)
	DF-5	10	HRD	7.00	186	(7.3)	5.6	45.6	(10.3)	51	(2.0)	1.08	(9.5)	36.9	324	(12.7)	3.57	(31.6)	64	45.4	(6.59)	9.2	(20.5)
	HRD Average			12.93	185	(7.3)	10.94	64.4	(14.5)	97	(3.8)	2.77	(24.5)	49.68	414	(16.3)	5.47	(48.5)	62	65.5	(9.50)	9.1	(20.2)
	Overall Average			**10.44**	**185**	**(7.3)**	**10.36**	**58.7**	**(13.2)**	**92**	**(3.6)**	**2.58**	**(22.8)**	**44.6**	**378**	**(14.9)**	**4.82**	**(42.6)**	**54**	**59.37**	**(8.6)**	**9.1**	**(20.3)**
	Standard Deviation			**5.70**	**2.14**	**(0.1)**	**3.12771**	**12.7**	**(2.8)**	**27**	**(1.1)**	**1.00**	**(8.9)**	**13.3**	**99**	**(3.9)**	**1.64**	**(14.5)**	**12**	**14.14**	**(2.1)**	**0.2**	**(0.5)**

***Data Filtered According to SAE J211/1 Requirements**

(green) Limited by Maximum Deflection Criterion (20 in.)

(yellow) Limited by Time of Contact

6 PRELIMINARY POST SIZE DETERMINATION

When the preliminary bogie tests were completed, it was necessary to adjust the post sizes for each species. The selected sizes needed to be large enough to give the post sufficient strength to rotate through the soil rather than fracture, but also be as small as possible to save on material costs. To determine this size, a statistical analysis of post strength was used along with two secondary methods, the static and the dynamic methods. The statistical analysis, called the probability method, was structured to limit the probability of failure of a guardrail system during a design limit impact to a defined level. The static method was designed to equate the capacity of the Douglas Fir and Ponderosa Pine posts to that of Southern Yellow Pine posts which had previously been accepted for use in guardrail systems. The dynamic method was based on allowable stress design, using the MOR from the knots category, historically the lowest, to assure that posts were large enough to endure the soil forces. The last two methods were used to verify the results of the first, and all three methods are presented below.

6.1 Probability Method

Initially, an acceptable level of risk was established. That level of risk was selected as a three percent chance that the structure would fail when a design limit impact occurred on a guardrail installed in strong soils, at any given location. Three percent may seem high, but the strong soil and extreme impact conditions that will be used in the full-scale and bogie testing have an impact on the failure level. The vast majority of soils across the nation would not be capable of developing resistance forces equivalent to those of the strong soil used in the tests. In addition, the impact conditions represent a worst case scenario of ran-off-road crashes. Those two factors considered, the risk of post failure would be dramatically lower for most roadside installations.

The next decision to be made was the determination of failure. One study, completed by Reid and Rohde [17-19], suggested that a standard guardrail system should meet the NCHRP Report 350 Test 3-11 requirements even after three consecutive posts failed. BARRIER VII was used to investigate the effects of weak posts on the MGS system in order to determine the appropriate failure criteria.

6.1.1 BARRIER VII Modeling

Barrier VII is a non-linear, 2-dimensional (2-D) computer simulation program that was used to model the guardrail system. The program was used in lieu of other vehicle-barrier impact simulation programs because of its extensive use and validation in previous impacts. The program has been used to model longitudinal barriers since 1980, and has been validated on a wide variety of systems including guardrail, guardrail transitions, flexible barriers, box beams, and timber railings. In addition, the use of BARRIER VII has been recommended in NCHRP Report 350, and, in some cases, has been accepted as a sufficient substitute for full-scale testing by the Federal Highway Administration [46].

6.1.2 MGS Model

The baseline MGS BARRIER VII model was taken from a previous model developed and validated by Kuipers [47]. The model had 173 nodes and 201 members, including 172 beam elements and 29 post elements. A typical model is presented in Appendix C along with an AutoCAD schematic of the model. Properties for the rectangular wood anchor posts, which differed from the steel posts found throughout the system, were not adjusted because the same anchors will be utilized in the new system.

The properties for the steel posts used throughout the remainder of the system were also left alone since bogie-soil behavior was unknown for the round posts. Initially, a modification was considered to adjust the longitudinal properties of the post to match the lateral properties since the soil behavior of a round post would be independent of the direction of impact. However, unlike steel posts, the round posts are able to rotate fairly easily around their vertical axis, greatly reducing their longitudinal force capacity. Since that magnitude of this reduction was not quantifiable, their longitudinal properties were also approximated based on the model's steel post definition. This seemed to be a reasonable assumption since the target behavior for the round posts was to be equivalent to a W152x13.4 (W6x9) steel post.

6.1.3 BARRIER VII Results

Simulations were completed on the system for models with 0, 1, 2, 3, and 4 consecutive weak posts. The weak post model was defined with the same parameters as a strong post except for its failure deflection. The weak post failure deflection was defined at 61 mm (2.4 in.) to assure that the posts failed. This deflection was based on soil bogie testing in which wood posts fractured at a very low deflection. Impact points were at 283 mm (9.375 in.) increments, beginning 953 mm (37.5 in.) upstream of the first weak post and ending 953 mm (37.5 in.) downstream of the last weak post.

The parameters collected from the simulations include maximum dynamic deflection, maximum rail tension, rail slope, and wheel snag. The rail slope is the maximum slope of the rail in the horizontal plane as shown in Figure 7, with the lateral direction being the y-axis and the longitudinal direction being the x-axis. The values were determined to give an estimate of the potential for pocketing. The steeper the rail, the greater the chance the vehicle will pocket. Since rail slope varies with the number of nodes used in its approximation, both a 3 node and 5 node analyses were completed.

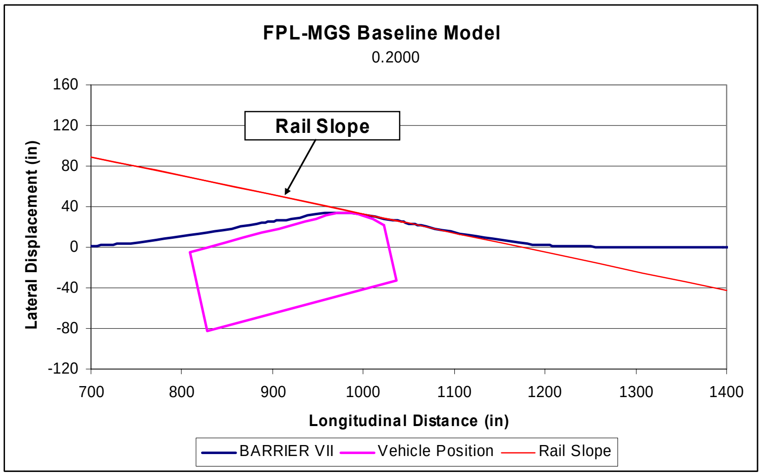


Figure 7. Rail Slope Diagram

Wheel snag parameters consist of two important values, snag and dy. Snag is the amount of overlap between the vehicle tire and the post transverse to the system at the ground level. The variable dy is simply the deflection of the post at the center height of the rail, which is used to determine the deflection of the post at the height of the snag calculation. Both are illustrated in Figure 8.

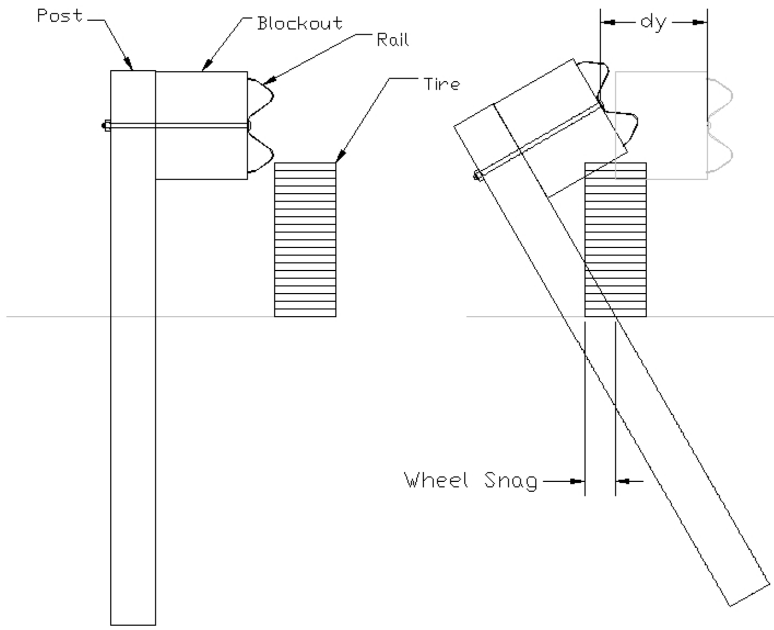


Figure 8. Wheel Snag Diagram

The maximum results are summarized in Table 17. This implies that the values from the various categories presented for each model are not necessarily from the same run, but rather the most critical for each category from any of the runs.

Table 17. FPL BARRIER VII Results Summary

No. Weak Posts	Maximum Deflection	Maximum Rail Tension	Pocketing Analysis		Snag Analysis **	
			3 Node	5 Node	Snag	dy
	(in.)	(kips)	(Rail Slope)		(in.)	(in.)
0	40.3	67.6	0.292	0.286	5.78	14.68
1	46.5	65.5	0.345	0.317	5.47	14.98
2	49.5	67.3	0.345	0.320	5.54	14.93
3	51.6	67.3	0.345	0.325	5.39	14.51
4	54.0	68.9	0.345	0.324	5.54	14.83

** Wheel snag was not reported when dy exceeded 15 in. because the post was considered to be broken.

The results from the FPL simulations show that there is no distinct point at which one additional failed post will cause the system to drastically fail. However, the general trend in the data shows that the more consecutive weak posts the system contains, the more severe the impact criteria. Maximum deflection, maximum rail tension, and maximum rail slope all show a general increase as the number of failed posts increased.

One interesting phenomenon was the decrease in rail tension from the baseline model to that with one, two, and three weak posts. This decrease was attributed to the longitudinal strength of the posts. When one post failed, the restraint on the rail was reduced, lowering the maximum rail tension. However, as more posts failed, the increased deflection caused the tension to increase once again.

Although the simulation did not identify a specific failure criterion, one still needed to be determined. Clearly the case with four weak posts was the worst. It exceeded the MGS baseline model in deflection by nearly 356 mm (14 in.), with the total deflection as high as 1372 mm (54 in.).

At some level, the maximum deflection will be so high that the system will need to be placed too far from the obstacle it is shielding to be feasible for use in many locations. Median widths, right-of-way distances, and bridge span lengths restrict the amount of deflection a guardrail system is allowed. Therefore, a maximum allowable deflection for the system was established at 1321 mm (52 in.). A larger maximum deflection could have been chosen, but the clearance needed for installation would also have increased. 1321 mm (52 in.) seemed to be a reasonable limit on the deflection.

The conclusion from the previous study by Rohde and Reid was that three consecutive failed posts would constitute an acceptable system, but four consecutive failed posts would not. This conclusion was based on engineering judgment and the results of BARRIER VII computer simulation completed in their study. This 4 post limit was also the result found by enforcing the 1321-mm (52-in.) maximum deflection criterion. Therefore, the probability that four consecutive posts would fracture prematurely needed to be less than three percent.

6.1.4 Post Reliability

If the probability of a single post failing is represented as P_f, it can be shown that the probability of four consecutive posts failing is $(P_f)^4$, which must be less than 0.03. Therefore, the probability of a single post failing, P_f, must be less than $(0.03)^{1/4} = 0.42$. For the purposes of the project, a maximum allowable P_f value of 0.4 was chosen.

The next step in the post size selection was to determine a minimum required force, or the minimum force that a post needed to resist if it were to rotate in the soil rather than fracture. Historical bogie testing results were examined and are presented in Figure 9. Bogie test nos. NPGB-4, 9, and 10 were conducted on W6x16 steel posts using a 1,016-mm (40-in.) embedment depth [27]. For these tests, the resisting force averaged approximately 35 kN (7.9 kips). To account for the local peaks exceeding this average value, as shown in Figure 9, a 20-percent increase was added to the force, thus making the minimum force for the current tests about 42 kN (9.5 kips).

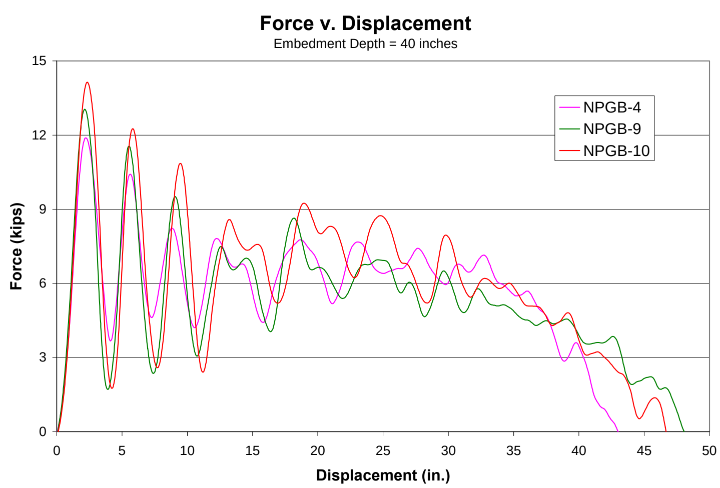
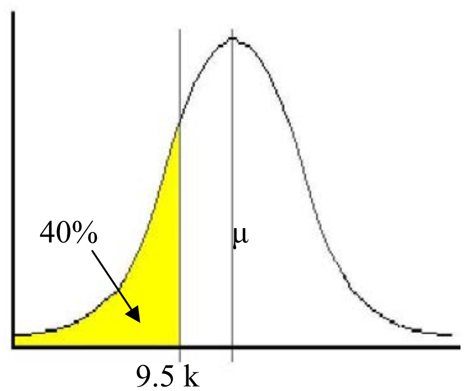


Figure 9. Force vs. Deflection NPGB - 4, 9, and 10

To meet the established probability requirements, 60 percent of the posts must exceed the 42-kN (9.5-kip) force limit. Using the average standard deviation and mean from the 15 dynamic bogie tests and assuming a normal distribution, the required mean peak force level that would return a 40 percent probability value of 42 kN (9.5 kips) was calculated for each species as follows.

$$X = \mu_X + Z\,\sigma_X$$
$$\mu_X = X - Z\,\sigma_X$$

$$Z = \Phi^{-1}(P) = -0.25$$
$$\Phi = \text{Standard Normal Distribution Function}$$
$$P = \text{Required Probability (0.4)}$$
$$\mu_X = \text{Required Sample Mean}$$
$$\sigma_X = \text{Sample Standard Deviation}$$
$$X = 40\%\ \text{Probability Force} \geq 9.5\ \text{kips}$$



$$\sigma_X = \begin{cases} 2.8\ \text{kips (Douglas Fir)} \\ 6.5\ \text{kips (Ponderosa Pine)} \end{cases}$$

$$\mu_X = \begin{cases} 10.2\ \text{kips (Douglas Fir)} \\ 11.2\ \text{kips (Ponderosa Pine)} \end{cases}$$

This required mean peak force was then used to calculate a required diameter of the posts based on the average dynamic modulus of rupture (MOR) values for each species. The equations used for the calculations are presented below followed by the results which are summarized in Table 18.

$$M = (L)(P)$$
$$L = \text{Impact Height}$$
$$P = \text{Impact Force}$$
$$\sigma_b = \text{MOR}$$
$$d = \sqrt[3]{\frac{32\,M}{\pi\,\sigma_b}}.$$

Table 18. Probability Method Calculation Summary

	L		P		σ_b		M		d	
	mm	(in.)	kN	(kips)	MPa	(kips/in.^{2})	kN-m	(kip-in.)	mm	(in.)
Douglas Fir	632	24.875	45.4	10.2	59.3	8.6	28.7	253.7	170	6.69
Ponderosa Pine	632	24.875	49.8	11.2	49.0	7.1	31.5	278.6	187	7.36

According to the probability method, 60 percent of 6.69-in. diameter Douglas Fir and 7.36-in. diameter Ponderosa Pine posts should reach or exceed 42 kN (9.5 kips) when impacted at 632 mm (24.875 in.) in a cantilever sleeve. This being stated, it should also be noted that the method used to determine these values has several limitations. First, the sample only included 15 posts, a very small sample considering the variability of wood. Second, the properties from the three categories were not weighted, but rather lumped together equally without consideration of their respective representation in the total post population. This meant that the mean determined from the testing may not have been an accurate representation of the total population. Third, lumping the data together also made it difficult to say how grading criteria affect the results.

6.2 Static Method

The second method used in determining post size was based on the results of the 40 static tests. This method began with the preliminary assumption that a 184-mm (7.25-in.) diameter Southern Yellow Pine (SYP) post was more than sufficiently strong for use in the W-beam guardrail system. This fact was based on successful full-scale crash tests conducted at TTI where 178-mm (7.00-in.) diameter and 184-mm (7.25-in.) diameter SYP posts were used in two barrier systems which met the NCHRP Report No. 230 and NCHRP Report No. 350 requirements respectively [32-34].

An alternate species was believed to have sufficient capacity if its static strength was found to be equal to that of a 178-mm (7.0-in.) diameter SYP post. The smaller diameter was selected because it passed the test. To generate an SYP data set, 15 static tests were conducted on the species in the same manner as the DF and PP posts. The 5th percentile, SYP capacity was found to be 24 kN (5.4 kips) based on a 5th percentile overall MOR of 27.5 MPa (3.993 ksi) and the 178 mm (7.0-in.) diameter. The 5th percentile value implied that 95 percent of 178 mm (7.0-in.) diameter SYP posts would reach a resisting force of 24 kN (5.4 kips) or higher. It should be noted that the 5th percentile was selected because it is commonly used in the timber industry. Although the results would differ, any percentile could have been chosen to complete the calculations.

The same standard was established for the other two species. In both Ponderosa Pine and Douglas Fir, 95 percent of the posts were required to reach or exceed a resisting force of 24 kN (5.4 kips). Using the 5th percentile MOR value determined for each of the two species, the diameter required to meet the force criteria was determined. Equations used in this method are provided below, followed by a summary of the calculations in Table 19.

$$M = (L)(P)$$
$$L = \text{Impact Height}$$
$$P = \text{SYP Impact Force (5.4 kips)}$$
$$\sigma_{\text{Static}} = \text{MOR}_{5\%}$$

$$d = \sqrt[3]{\frac{32\,M}{\pi\,\sigma_{Static}}}$$

Table 19. Static Method Calculation Summary

	L		P		σ_b		M		d	
	mm	(in.)	kN	(kips)	MPa	(kips/in.^{2})	kN-m	(kip-in.)	mm	(in.)
Douglas Fir	631.83	24.875	24.0	5.4	38.0	5.516	15.2	134.3	160	6.28
Ponderosa Pine	631.83	24.875	24.0	5.4	24.1	3.497	15.2	134.3	186	7.31

The method suggests that 95 percent of the posts with a diameter of 160 mm (6.28 in.) for Douglas Fir or 186 mm (7.31 in.) for Ponderosa Pine will reach or exceed a static load of 24 kN (5.4 kips) at the 632 mm (24.875-in.) load height. As with the probability method, some limitations exist. Again, the properties for the three categories were lumped together with the same consequences as before. Although a normal distribution was assumed, the parameters used to develop the distribution may not have been thoroughly representative of the population.

6.3 Dynamic Method

The third and final calculation method combined parts of each of the previous calculation methods. In this method, the average MOR value determined for the knots category for both species was used to determine a diameter that would be capable of carrying a 44.5-kN (10-kip) applied load.

The increased load was determined from the results of tests NPGB 4, 9, and 10 as before, but was selected to be high enough to exceed the majority of the local peaks in the force data. Previously, the estimated soil force was based on a 20 percent increase from the average rather than the magnitudes of individual peaks.

Although the baseline posts showed the lowest MOR for both species, the knots category was selected as the critical category. This was done because it was believed that the baseline results were misleadingly low due to the relatively low ring density of the posts within the category. It was suspected that for a more similar average ring density, the MOR for the knots category would fall well below that for the baseline category. The equations used for the dynamic method are shown below, followed by a summary of the calculations in Table 20.

$M = (L)(P)$

L = Impact Height

P = Impact Force

$\sigma_b = MOR_{\text{Dynamic Knots}}$

d = diameter

$$d = \sqrt[3]{\frac{32\,M}{\pi\,\sigma_b}}$$

Table 20. Dynamic Method Calculation Summary

	L		P		σ_b		M		d	
	mm	(in.)	kN	(kips)	MPa	(kips/in.^{2})	kN-m	(kip-in.)	mm	(in.)
Douglas Fir	631.83	24.875	44.5	10	60.9	8.83	28.1	248.8	168	6.6
Ponderosa Pine	631.83	24.875	44.5	10	44.8	6.5	28.1	248.8	185	7.3

The dynamic method was based on allowable stress design, unlike the other two methods that were founded on probability. This method concluded that the critical knots category, with an average diameter of 168 mm (6.6 in.) for Douglas Fir and 185 mm (7.3 in.) for Ponderosa Pine, will have an average dynamic capacity of 44.5 kN (10 kips) at 632 mm (24.875 in.). Again, the method has several drawbacks, the first of which is the unknown population strength distribution. The knots category may represent 90 percent of the population, in which case 45 percent of the posts would not reach the suggested capacity. In turn this would result in a 4.1 percent chance of failure in the full system due to four consecutive posts failing. On a similar note, the distribution of the other two categories was not considered. A portion of the posts in those categories may also fall below the required capacity, depending on the average and magnitude of the standard deviation within the category.

6.4 Post Size Conclusion and Summary

After considering the results from all three methods, a final size was determined for each of the wood species. Final suggested diameters were rounded up to the nearest quarter of an inch for manufacturing purposes. The final diameters were based on the probability method, but were also supported by the dynamic method which resulted in similar minimum diameter values that would be identical after rounding. The static method resulted in a slightly smaller diameter for Ponderosa Pine, and a significantly smaller diameter for Douglas Fir. Similarities between the results of the three methods offered assurance that diameters determined using the probability method were reasonable and accurate. The sizes determined with each method and the suggested sizes are presented in Table 21 below. These suggested sizes should be used in a second round of cantilever testing to assure that the MOR does not vary with post diameter.

Table 21. Post Diameter Calculation Summary

Suggested Diameter (in.)				
Species	**Probability Method**	**Static Method**	**Dynamic Method**	**Suggested**
Douglas Fir	6.69	6.28	6.60	**6.75**
Ponderosa Pine	7.36	7.31	7.30	**7.50**

7 INERTIAL EFFECTS

7.1 Introduction

As stated previously in Section 6.2, the most important parameter of the bogie testing was the peak force generated by the post before fracture. If the peak post capacity exceeds the peak resisting force of the soil, the posts should be capable of rotating rather than fracturing. Preliminarily, this force was selected as the highest peak of the filtered force verses time plot, but after the data was processed, analyzed, and preliminary post sizes selected, questions arose with regard to its appropriateness.

A sample raw acceleration plot is presented in Figure 10. The bogie acceleration trace exhibits two large distinct and separate acceleration peaks. The question was, is wood capable of behaving like this plot suggests?

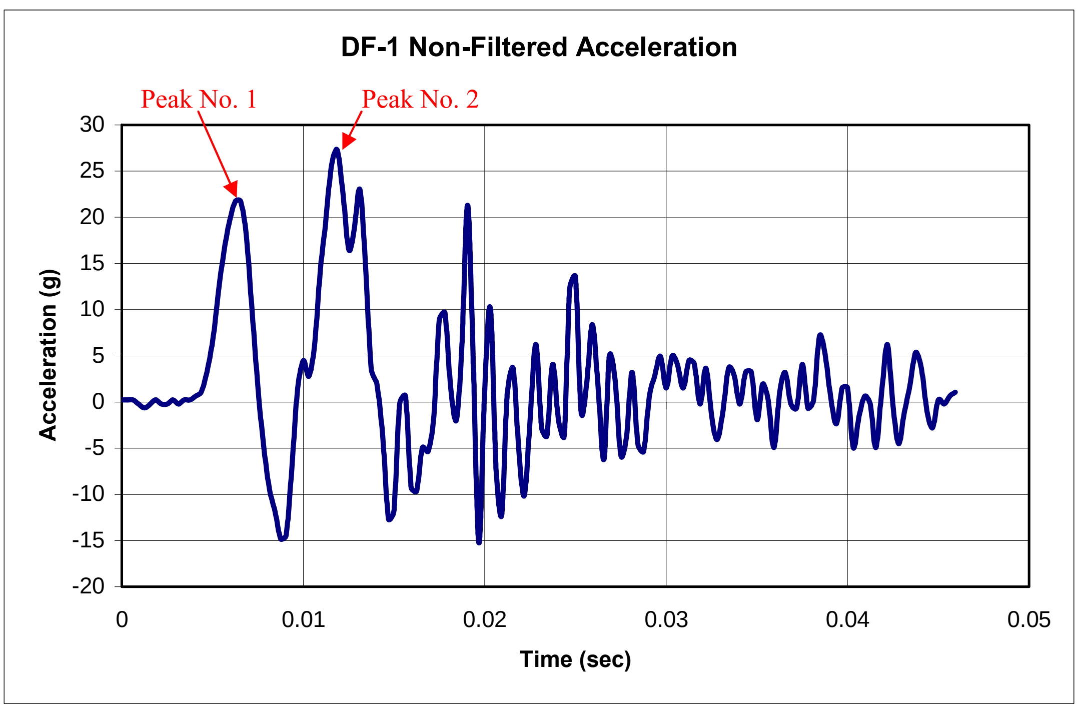


Figure 10. Bogie Test DF-1 Non-Filtered Acceleration

The data shown in Figure 10 suggested that the wood post reached a peak force, relaxed, and then reached a second peak force, sometimes higher and sometimes lower than the first. The cases in which the second peak was lower than the first suggest that the fibers reached some maximum stress value, relaxed, and then failed at some stress value lower than the maximum reached previously.

Another possible explanation of this behavior was a sequential failure in which the outer fibers fractured, allowing increased deflection in the post. As the post deflected farther, the layers failed sequentially at lower and lower peak force values. If this was indeed the case, a clear failure should have been evident as the peak force was reached. In this explanation, as a wood specimen begins to bend, tensile and compressive stresses develop in the wood fibers, with the maximum stress occurring at the extreme edges of the cross section. When the fibers within the wood reach their ultimate strength or stress, those fibers will fracture and carry no load at all. This behavior is much different than that observed in ductile materials, such as mild steel. As the fibers fracture, the effective cross section is reduced ring by ring, and the bending moment capacity gets smaller and smaller. This suggests that the posts should reach some peak force value, at which the outer fibers begin to fail, and then the force should drop off rapidly as the cross section shrinks. Such behavior cannot explain the phenomenon shown in Figure 10, especially if the first peak exceeded the second.

Although the second explanation is a clear possibility, typical wood behavior suggested a much different performance than the first explanation. Wood typically behaves in a very brittle manner, with a near linear stress-strain relationship. This means that the stress in the wood fibers should increase until failure at their ultimate stress. If the applied stress never exceeds the ultimate capacity of the wood, the fibers should not break. If the applied stress was removed and reapplied, the stress in the fibers should decrease, and then increase until the failure stress or the maximum applied stress was reached. They should never fail at a stress below that already reached since it in turn must have been below the ultimate strength if the fibers did not fracture.

7.2 Fracture Time Investigation

To investigate this phenomenon further, the high-speed digital video footage from the post bogie tests was studied. The videos were used to identify the point at which the outer fibers in the posts clearly failed. In many tests, this failure point was very apparent and took place between two consecutive frames. For those tests, the numbers of the two consecutive frames were recorded along with the number of the impact frame or the frame in which the bogie first contacted the post. Examples of all three frames are shown in Figure 11, Figure 12, and Figure 13 for a post with the critical region painted white to show the fracture very clearly. Figure 11 depicts the frame at impact, Figure 12 shows the frame prior to post fracture, and Figure 13 shows the frame immediately after post fracture.

Figure 11. Bogie-Post Impact – Frame 102

Figure 12. Post Bending Prior to Fracture - Frame 107

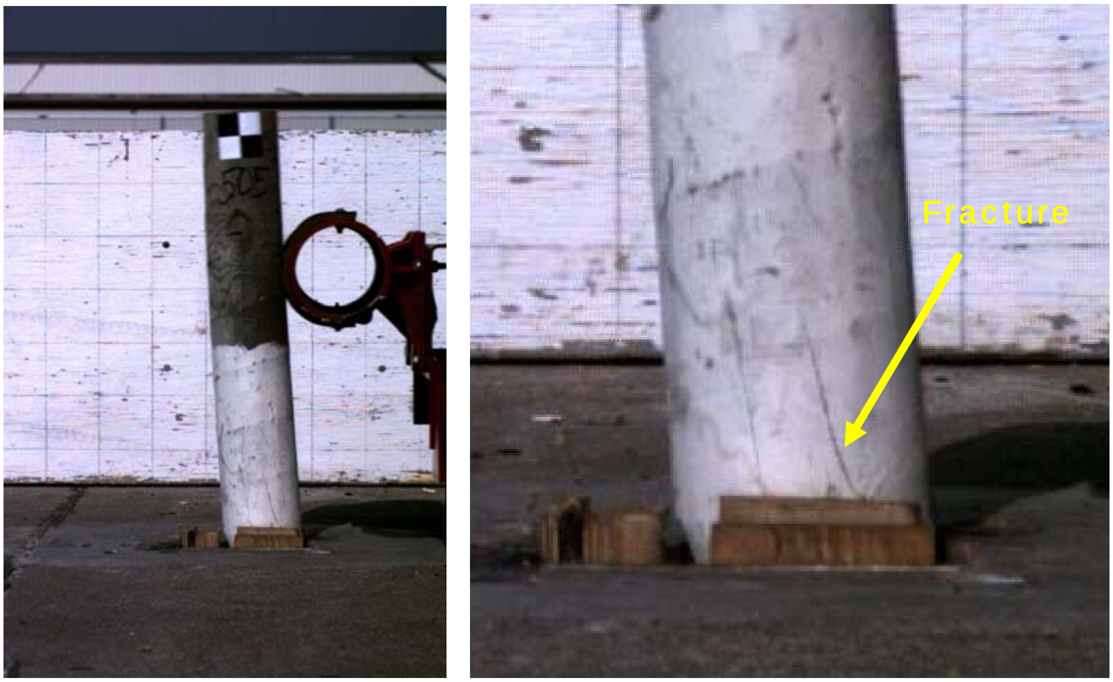


Figure 13. Post After Fracture - Frame 108

The frame numbers from the three figures were also used to calculate the time between them. For instance, since the camera recorded at a rate of 500 frames per second, the time between consecutive frames is approximately 0.002 seconds. For test no. DF-1, the three frame nos. were 144, 147, and 148. Therefore, the time between impact and frame no. 147 was 0.006 seconds and the time between frame nos. 147 and 148 was 0.002 seconds. Plotting these times on the longitudinal acceleration plots, with the first rise in acceleration considered as the impact, will show where the fractures occurred relative to the acceleration peaks. A plot of this comparison for test no. DF-1 is shown in Figure 14.

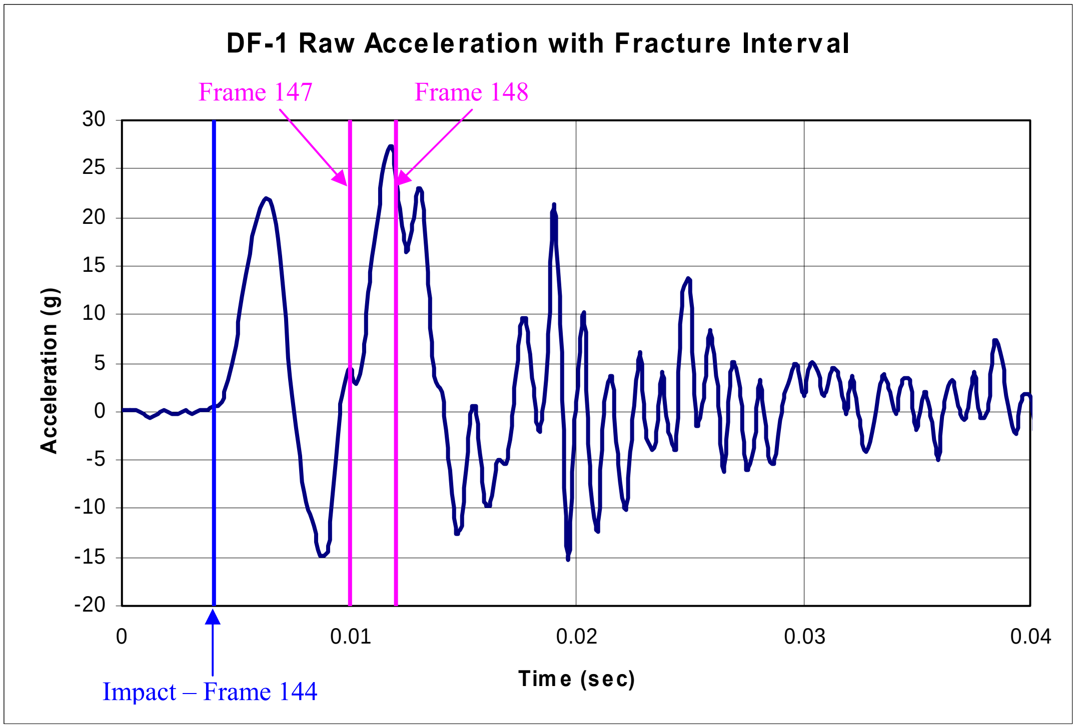


Figure 14. DF-1 Raw Acceleration with Fracture Interval

Similar plots are shown below in Figure 14 through Figure 39 for the remainder of the round one post tests in which a visible fracture was present. Impact is not labeled on these plots, but is always taken as the first rise in acceleration, similar to the plot of test no. DF-1. Plots containing more than two frame lines displayed more than one distinct fracture with a fracture occurring between each pair of lines.

Before considering the plots in detail, attention should be drawn to two inaccuracies that may affect the analysis. The first was the inaccuracy in determining the impact time. Although the frame selected as the impact frame was the first frame showing contact between the post and the bogie, it did not mean that the time associated with that frame was the time of the first contact. In fact, the initial impact could have occurred up to 0.002 seconds prior to that frame. This meant that the fracture window could shift up to 0.002 seconds to the right, in some cases shifting to encompass the maximum acceleration peak. This is shown by the additional shading in Figure 18. The second inaccuracy was the visibility of the fracture. As stated, several tests did not exhibit a visible fracture. Hence, the first fracture may not have been visible initially, and the broken fibers only became visible after the second or third fracture event. This may explain some cases such as that of Figures 20, 23, 25, 29, 33, 38, and 39 in which the fracture interval as shown did not make sense even including a 0.002 second shift.

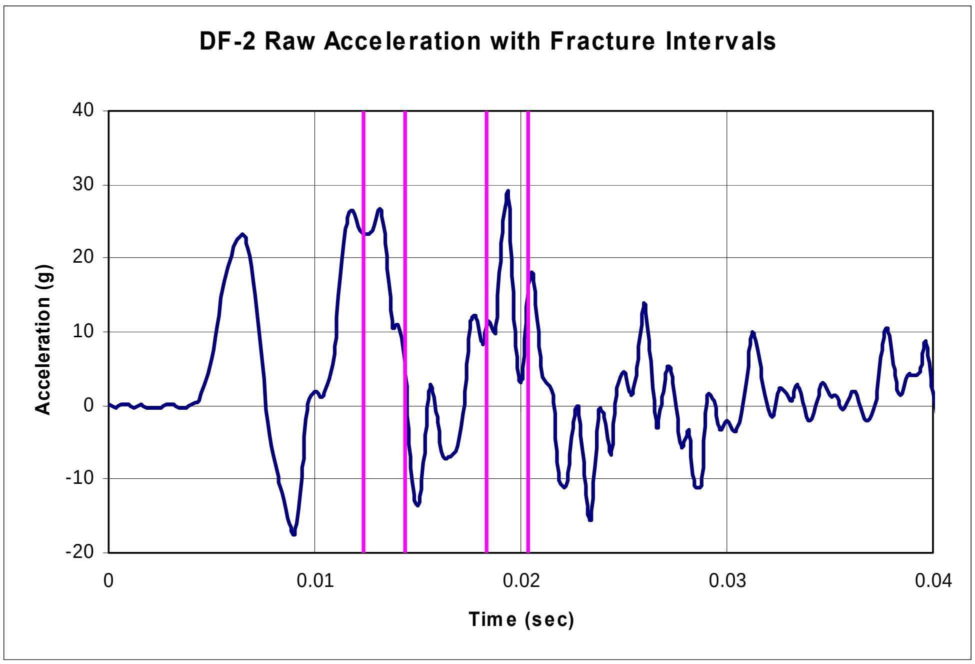


Figure 15. DF-2 Raw Acceleration with Fracture Intervals

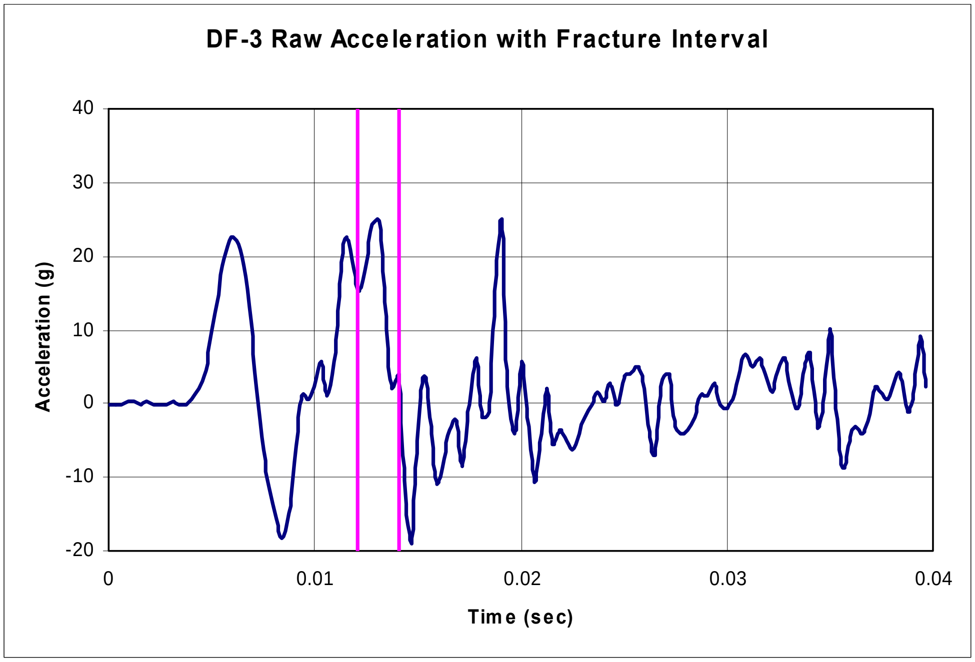


Figure 16. DF-3 Raw Acceleration with Fracture Interval

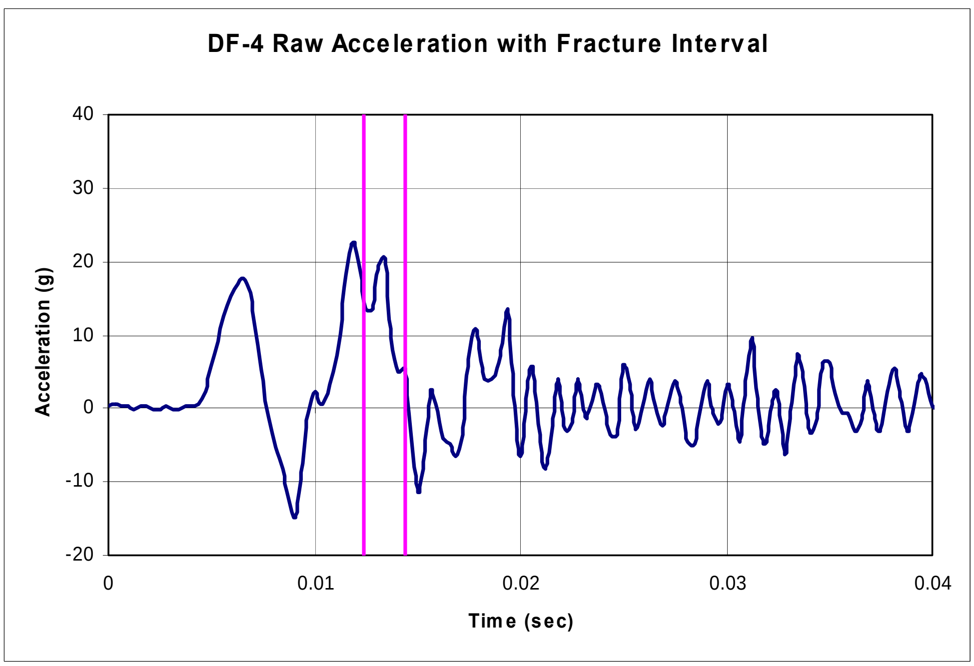


Figure 17. DF-4 Raw Acceleration with Fracture Interval

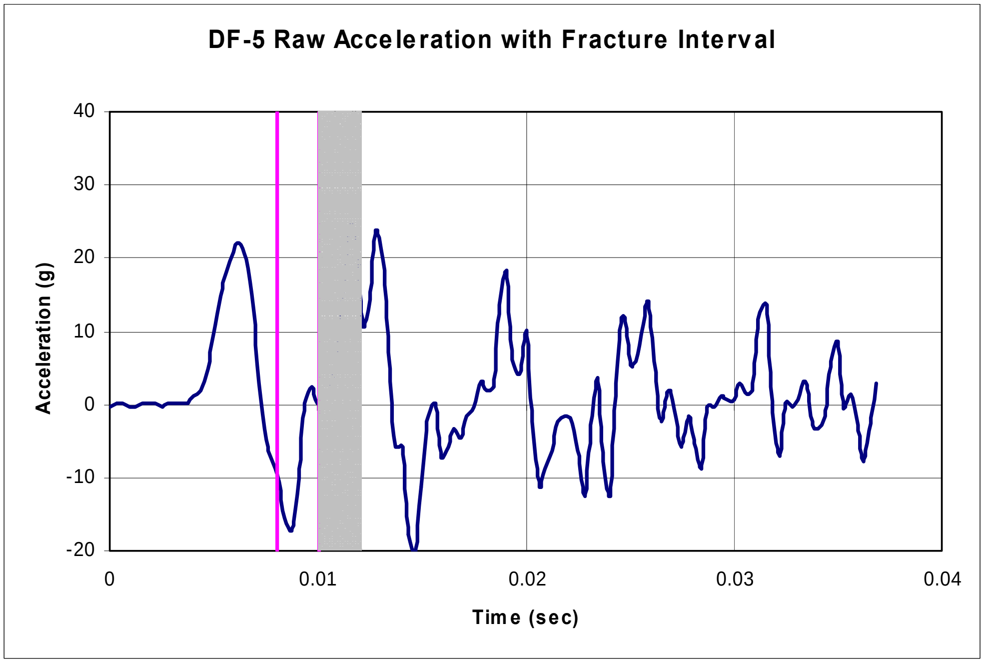


Figure 18. DF-5 Raw Acceleration with Fracture Interval

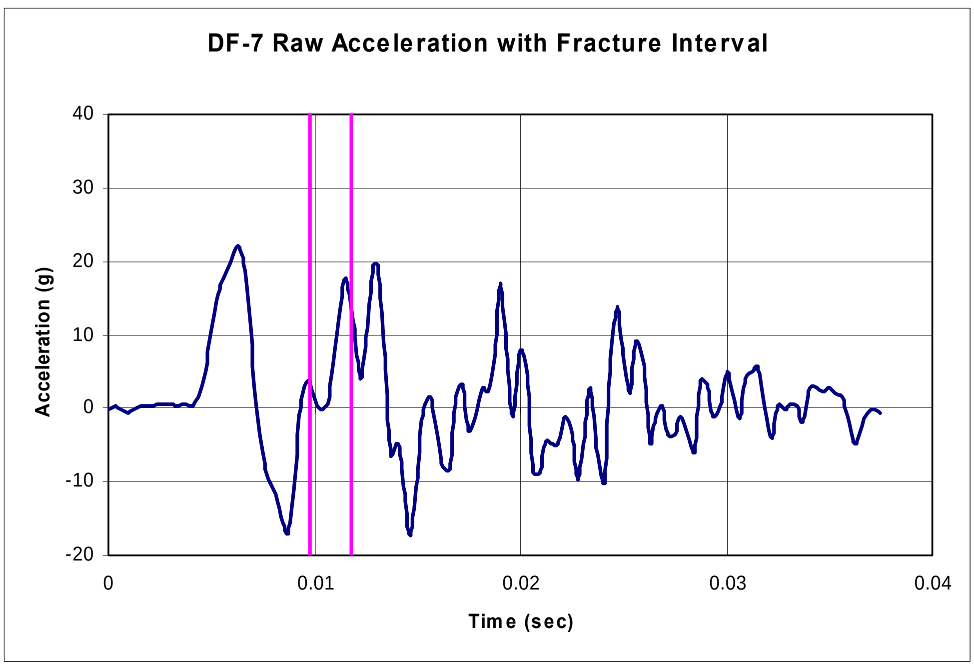


Figure 19. DF-7 Raw Acceleration with Fracture Interval

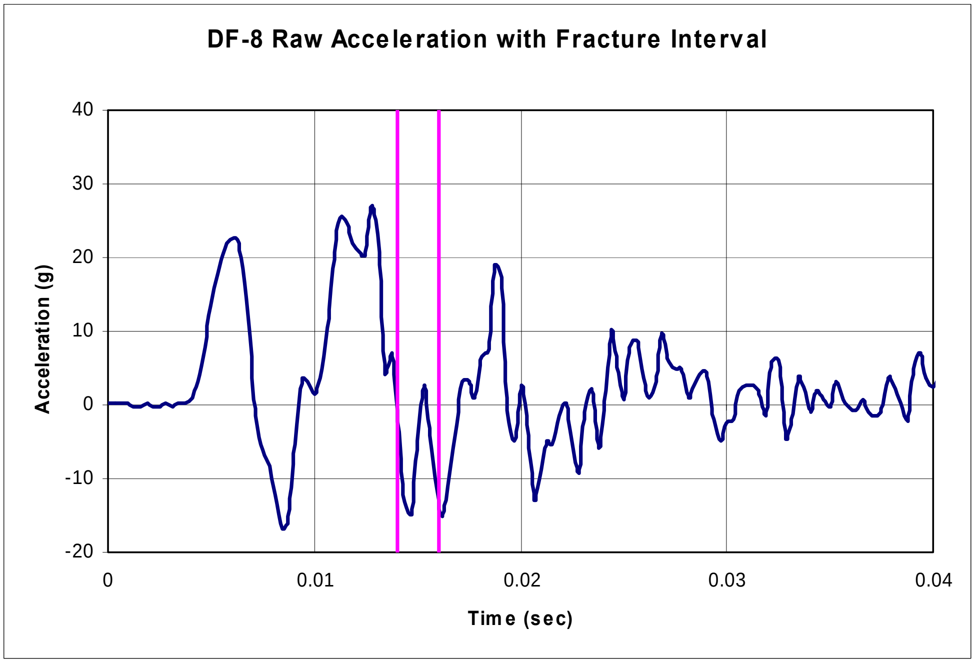


Figure 20. DF-8 Raw Acceleration with Fracture Interval

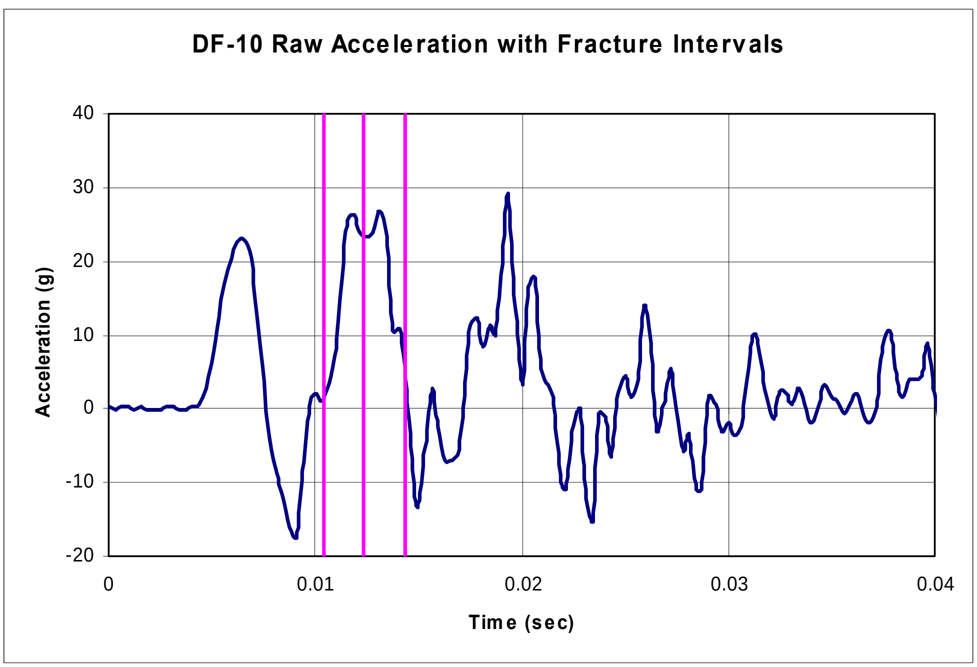


Figure 21. DF-10 Raw Acceleration with Fracture Intervals

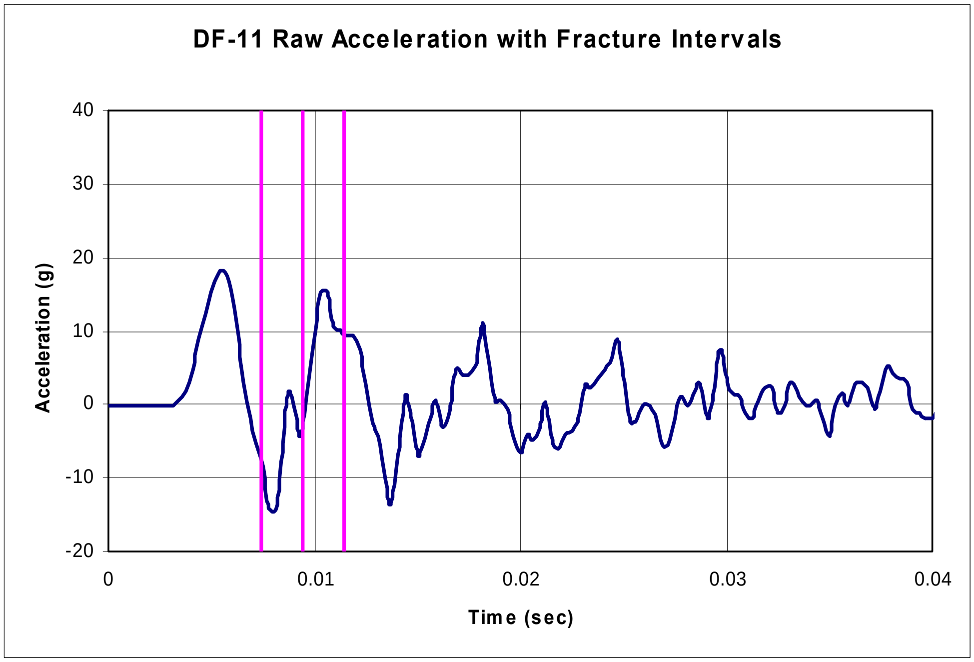


Figure 22. DF-11 Raw Acceleration with Fracture Intervals

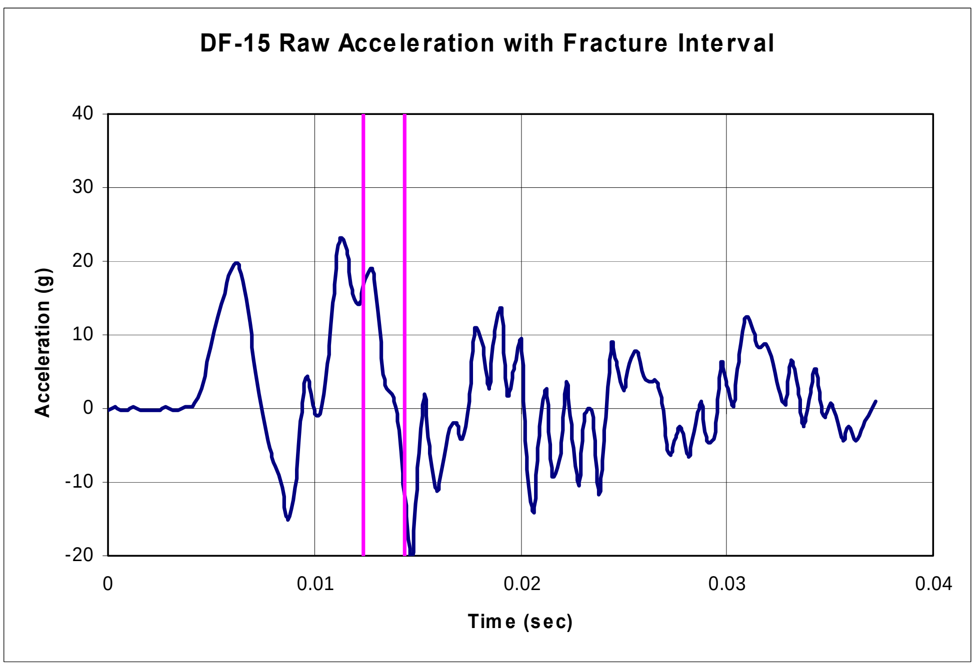


Figure 23. DF-15 Raw Acceleration with Fracture Interval

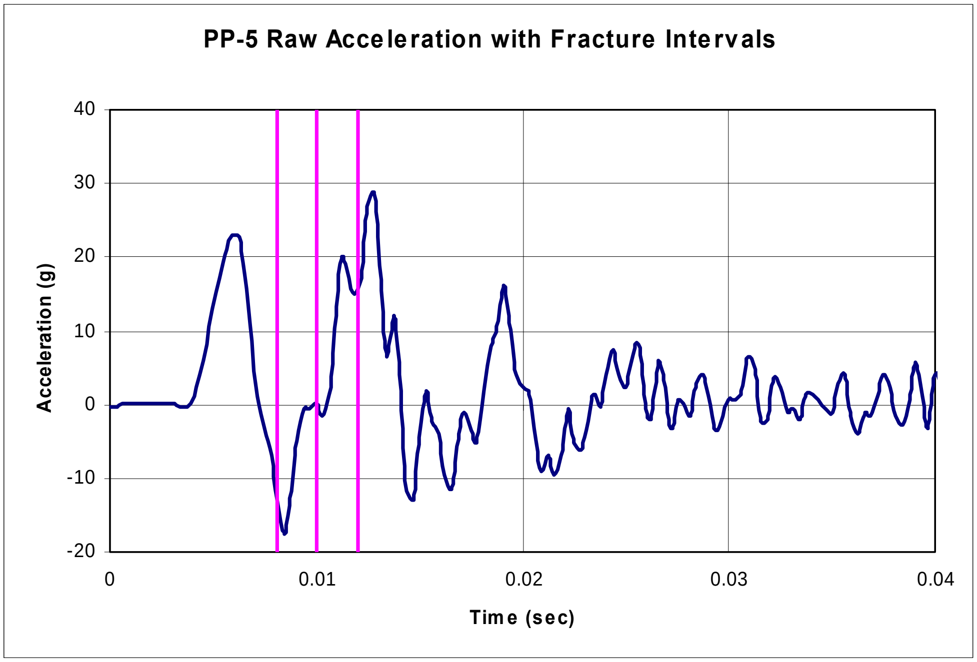


Figure 24. PP-5 Raw Acceleration with Fracture Intervals

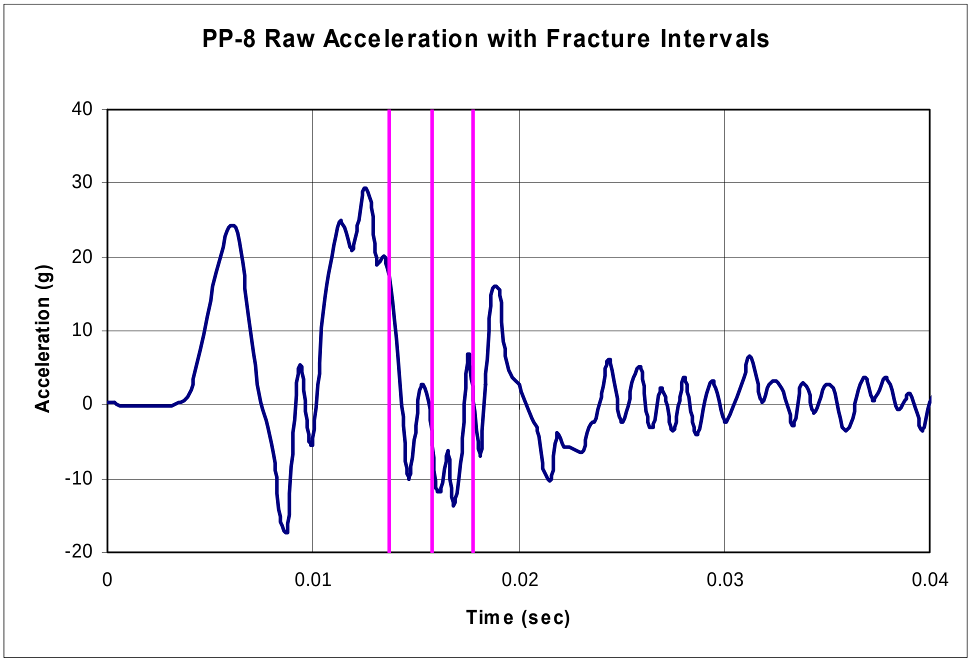


Figure 25. PP-8 Raw Acceleration with Fracture Intervals

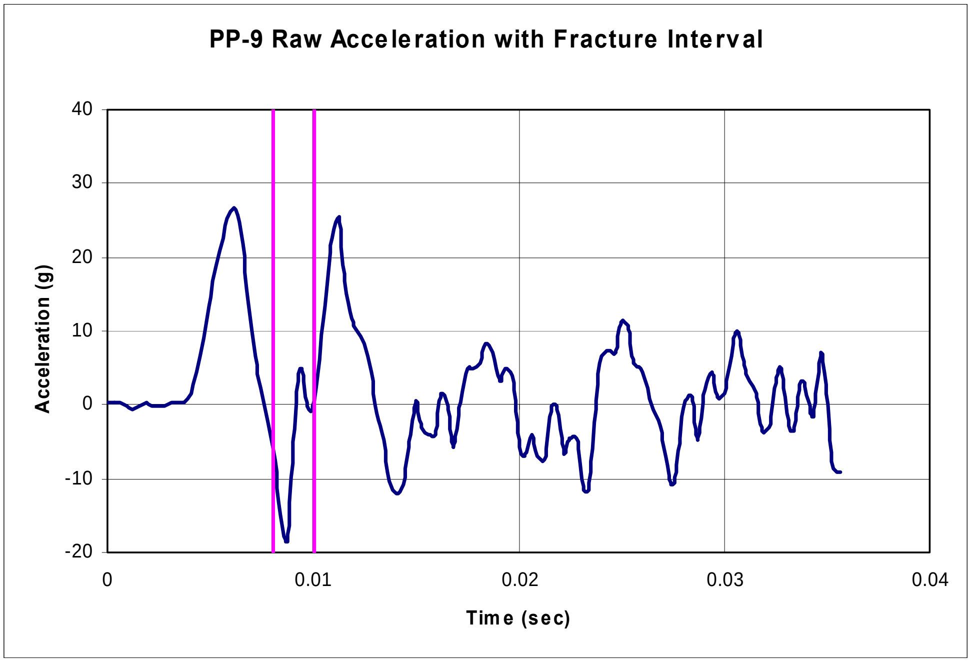


Figure 26. PP-9 Raw Acceleration with Fracture Interval

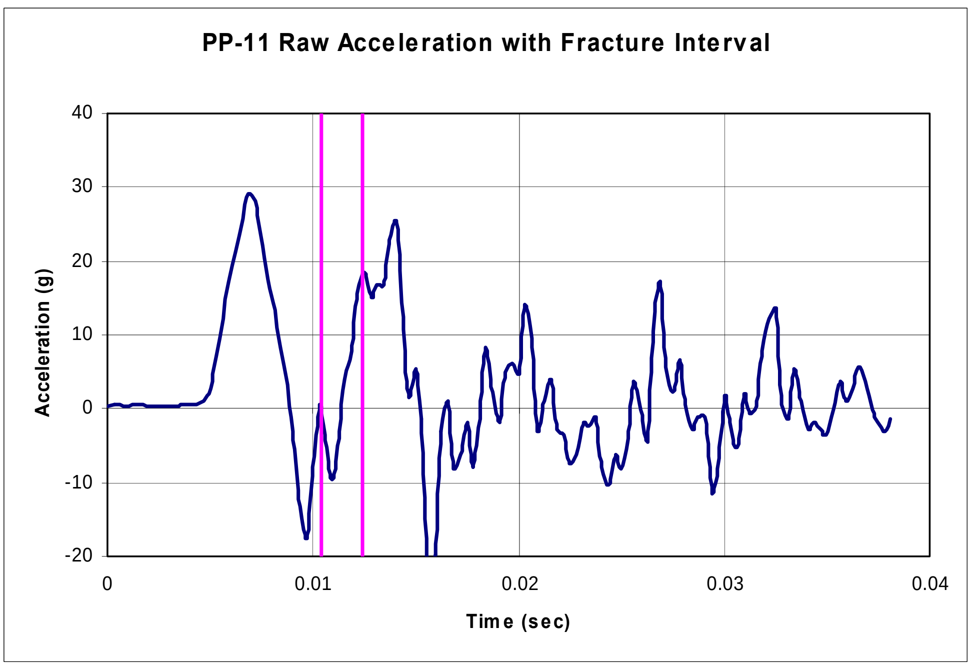


Figure 27. PP-11 Raw Acceleration with Fracture Interval

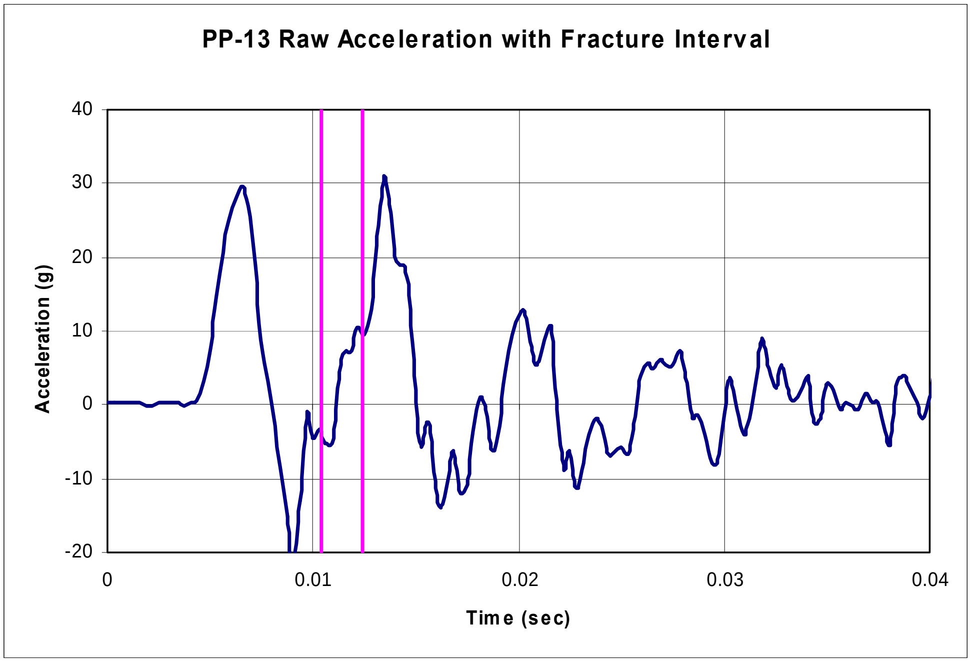


Figure 28. PP-13 Raw Acceleration with Fracture Interval

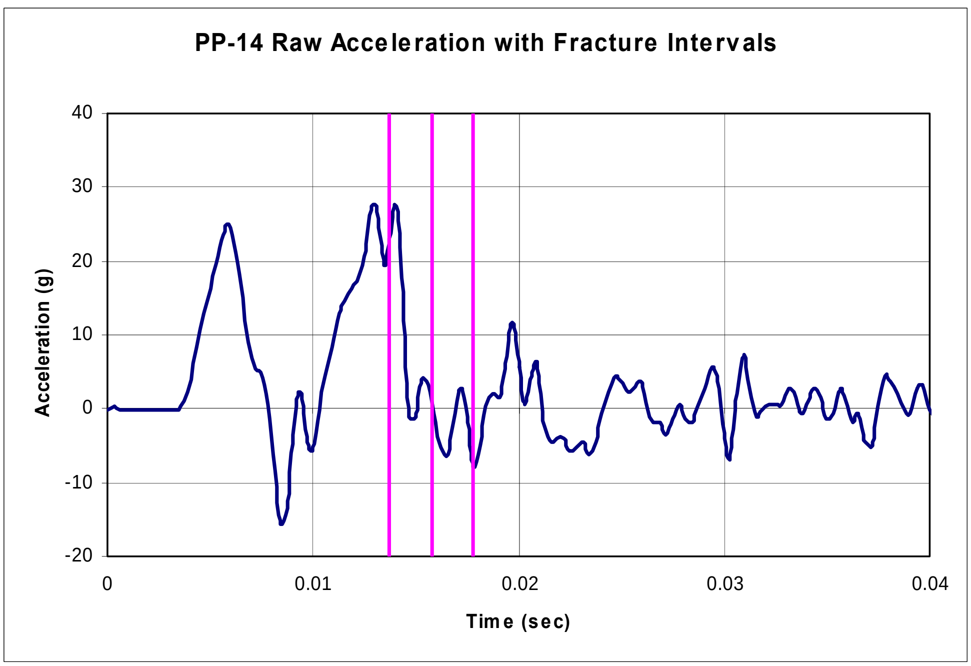


Figure 29. PP-14 Raw Acceleration with Fracture Intervals

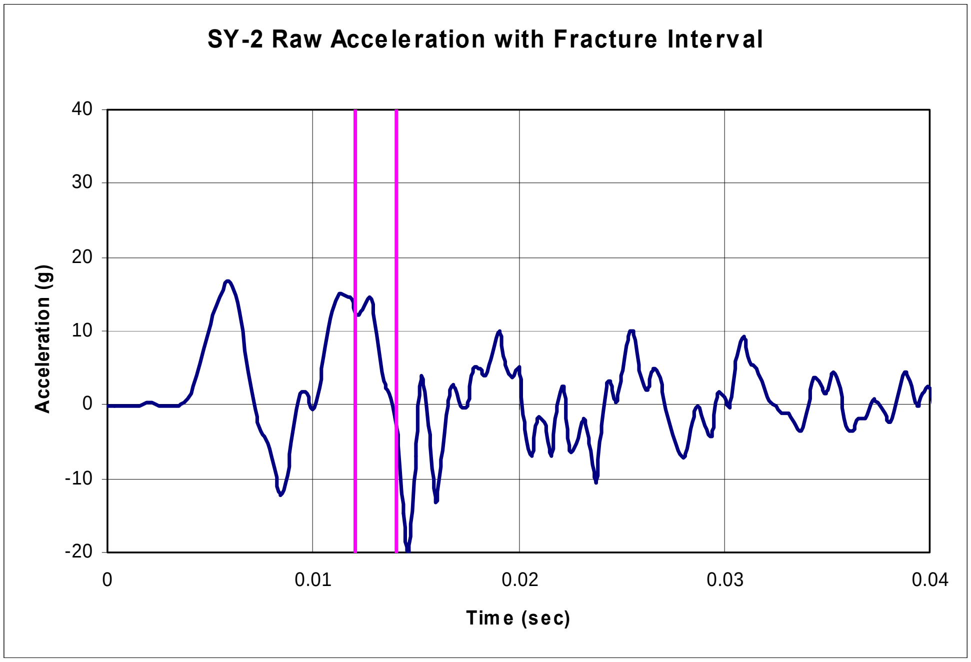


Figure 30. SY-2 Raw Acceleration with Fracture Interval

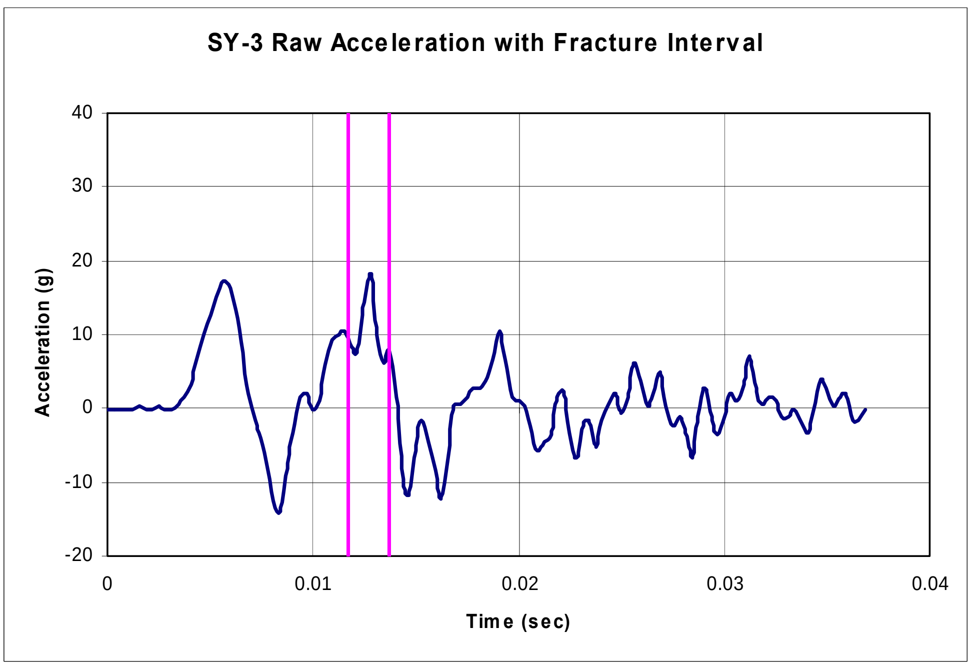


Figure 31. SY-3 Raw Acceleration with Fracture Interval

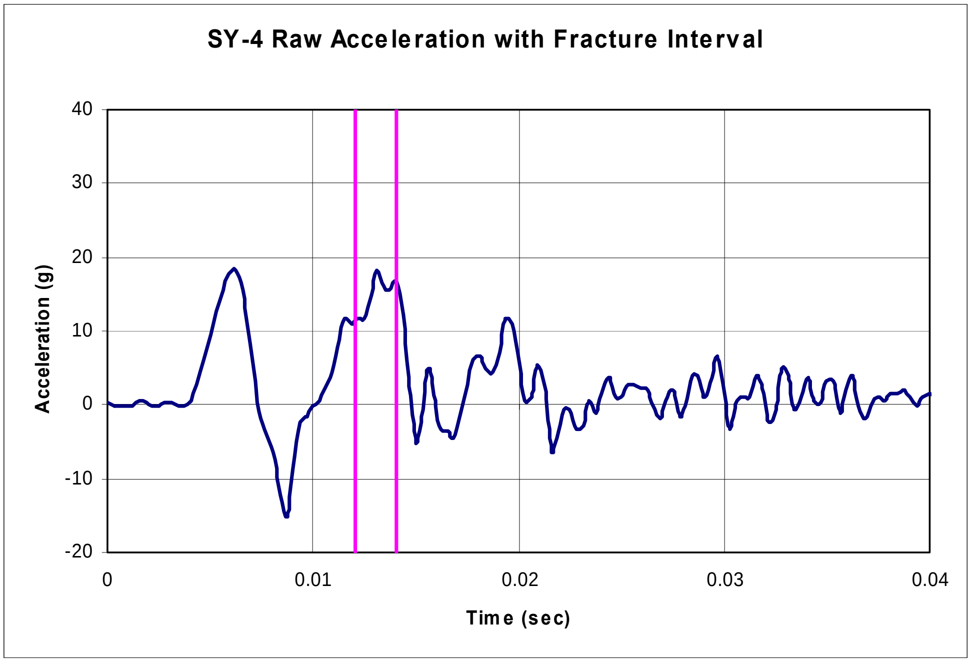


Figure 32. SY-4 Raw Acceleration with Fracture Interval

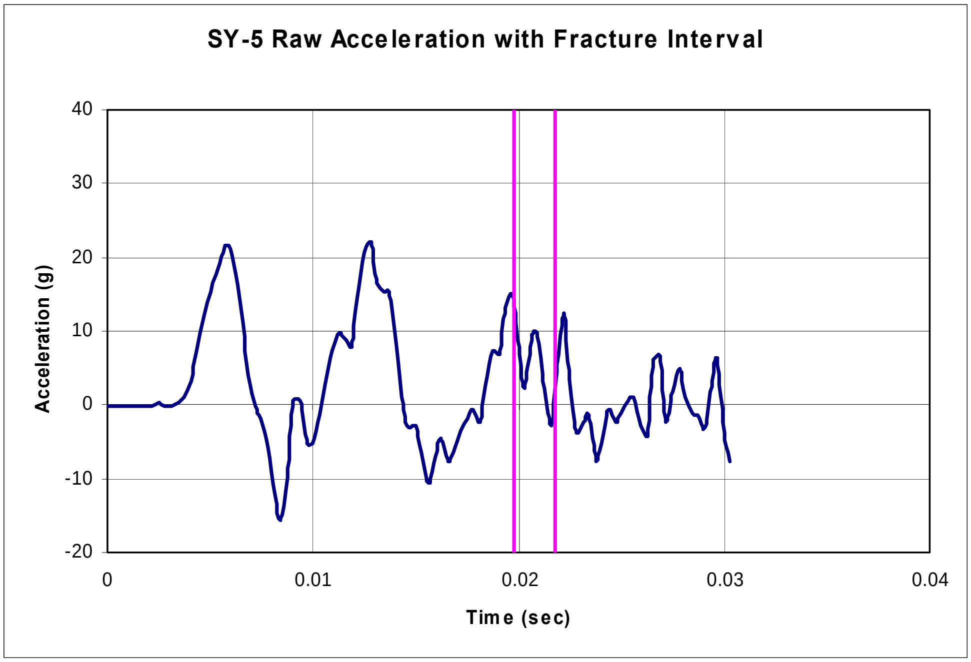


Figure 33. SY-5 Raw Acceleration with Fracture Interval

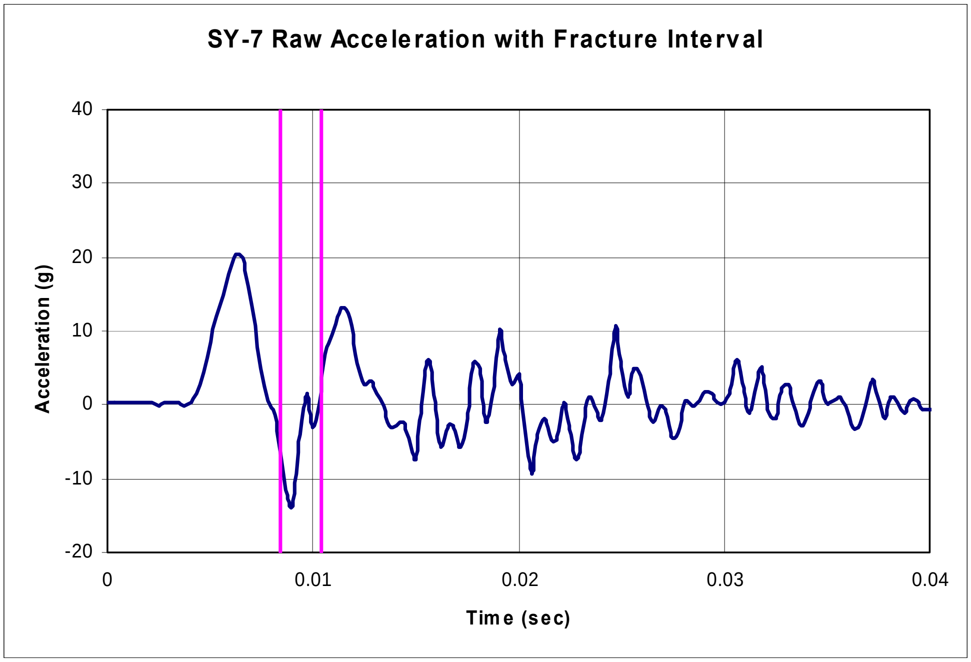


Figure 34. SY-7 Raw Acceleration with Fracture Interval

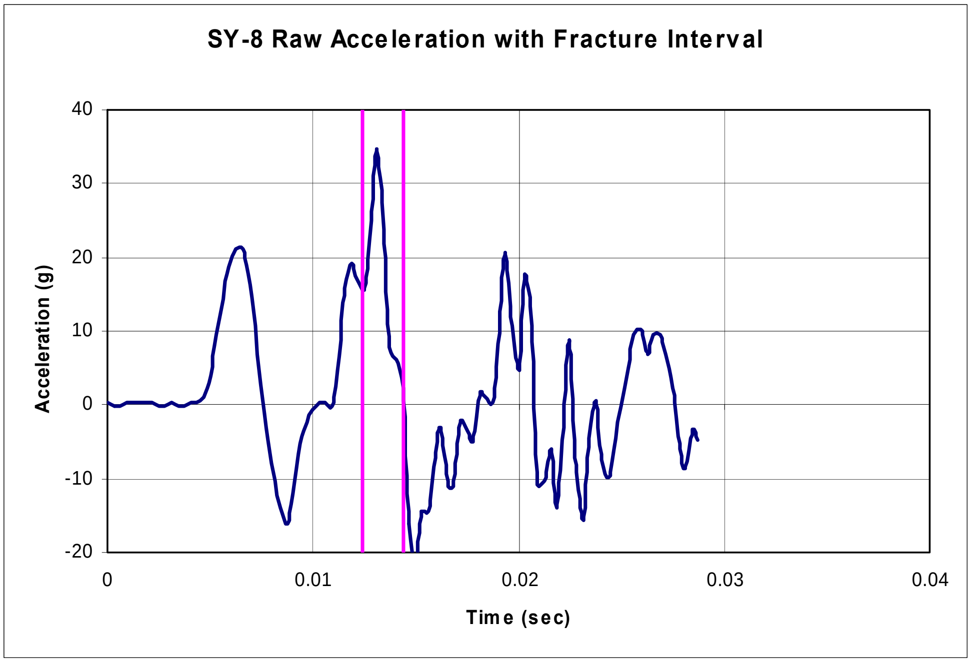


Figure 35. SY-8 Raw Acceleration with Fracture Interval

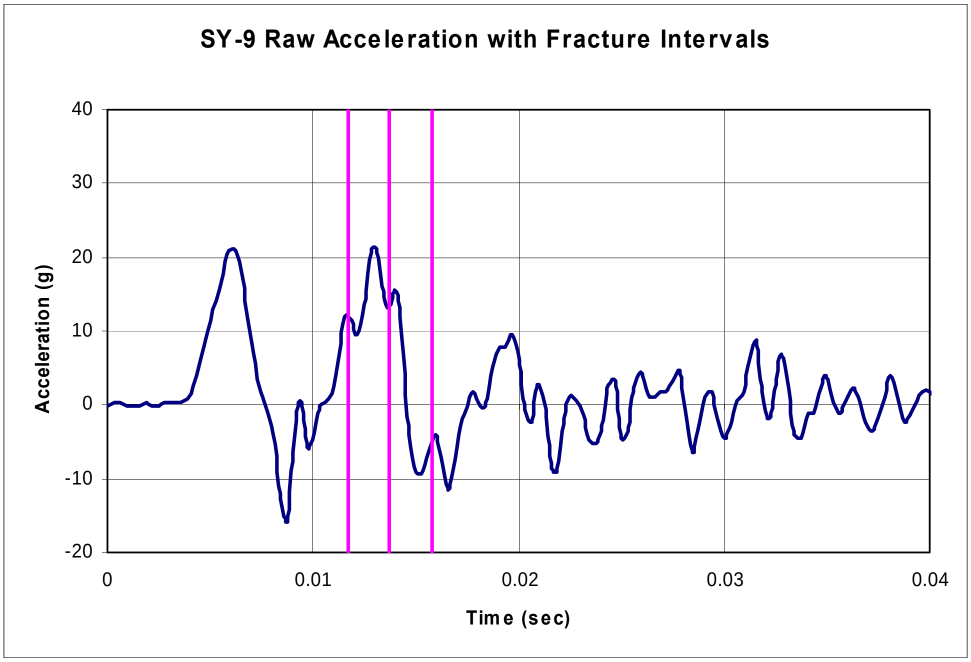


Figure 36. SY-9 Raw Acceleration with Fracture Intervals

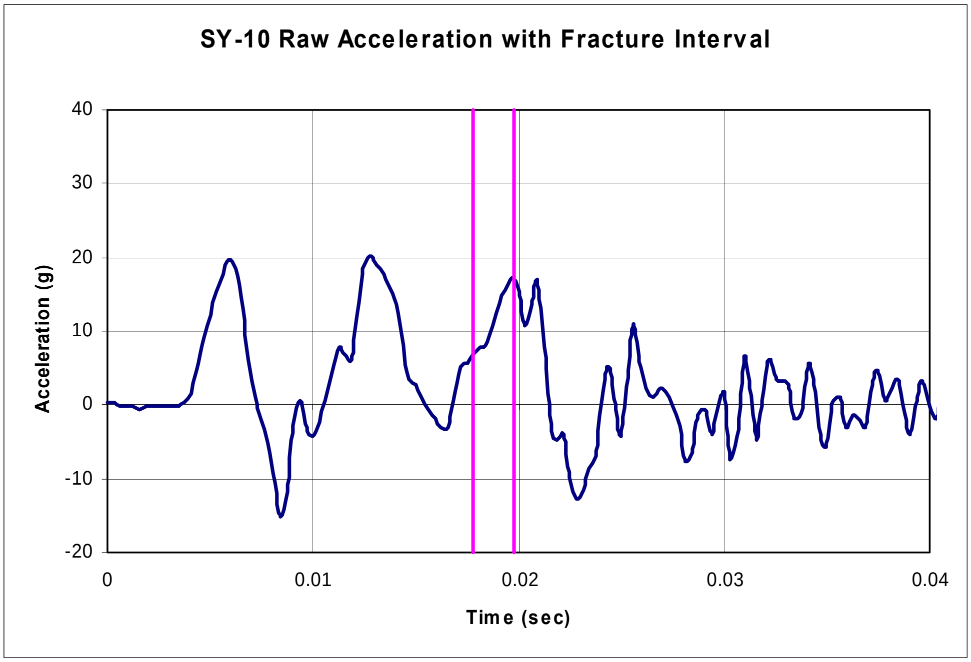


Figure 37. SY-10 Raw Acceleration with Fracture Interval

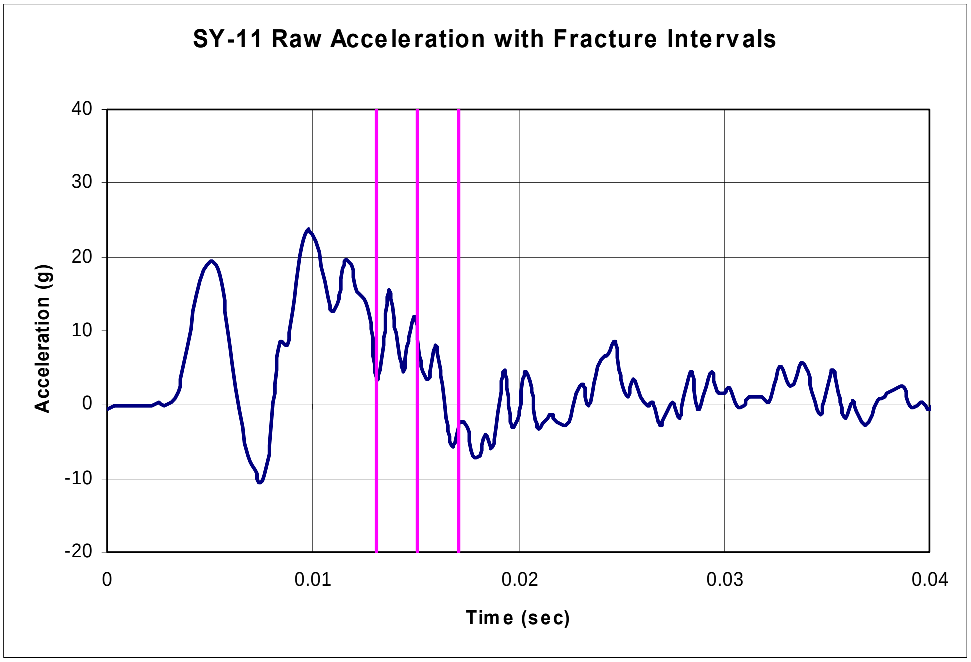


Figure 38. SY-11 Raw Acceleration with Fracture Intervals

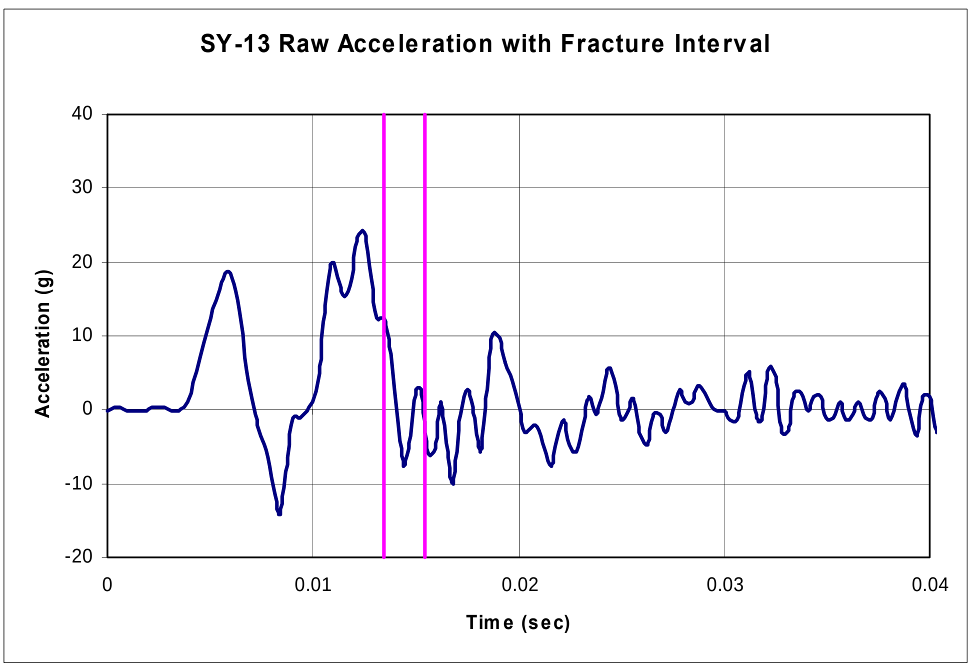


Figure 39. SY-13 Raw Acceleration with Fracture Interval

If the initial peak force was the maximum, and the post was indeed bending during that time, it should have failed during that spike rather than at a subsequent lower spike. However, none of the tests exhibited this behavior. This will be discussed in Section 7.3.

7.3 Possible Explanation – The Inertial Spike Theory

7.3.1 Explanation and Physical Description

When completing the bogie tests with the posts inserted in a fixed sleeve, some compliance must have existed between the post and the sleeve. This compliance occurred as a result of the shimming methods used to more rigidly fix the post in the foundation as well as from the variability in the cross section and straightness of the post. If the posts were perfect cylinders, the compliance in the system might have been negligible. However, when using wood posts, it was not possible to shim the post so every inch of its length was rigidly fixed.

Assuming this compliance exists, it would allow some, initial, free rotation and translation of the post as it was impacted by the bogie. Since the post was at rest, some initial force would be required to cause this motion, and the impulse of such a force should be equal to the change in momentum of the post, or its total momentum since the post began at rest.

If, during this initial rotation and translation, the posts were not bending, but rather just moving, the wood fibers in the posts would not be under any significant stress. In this case, the entire initial impulse force from the bogie was causing the post to move but not bend. Therefore, the initial impulse magnitude would have no meaning in relation to the strength of the posts.

7.3.2 Impulse and Analysis

The first pieces of supporting evidence were the acceleration trace vs. fracture time plots, which strongly supported the inertial spike theory. As shown in the plots, none of the failures occurred during the initial acceleration spike. Rather, the failures generally took place at a global or local peak sometime after the initial spike.

The next piece of supporting evidence was a simple impulse-momentum calculation. If the first spike was indeed caused by the inertia of the post, the impulse from the spike should have been equal to the change in momentum of the post. To investigate this comparison, the angular momentum of each post was calculated, converted to linear momentum, and compared to the impulse of the initial force spike from the acceleration trace. The momentum calculations were made assuming that: (1) each post rotated at the ground level with the impact height of each post moving at the initial velocity of the bogie head and (2) the mass of each post was distributed evenly throughout its length. The momentum calculation is shown below [48]. The calculated values and the comparisons for each test are presented in Table 22 through Table 24.

The momentum to impulse ratio clearly shows that the two values are very close for each test. The Douglas Fir tests appear to be the most different, with the change in momentum averaging 83 percent of the impulse. For the Ponderosa Pine and Southern Yellow Pine species, the average difference is much smaller. Change in momentum averaged 107 percent of the impulse for Ponderosa Pine, and 100 percent for the Southern Yellow Pine. The similarity of the results strongly supports the inertial spike theory.

$$\omega = \frac{V}{H_I}$$

V = Initial Bogie Velocity

H_I = Impact Height

ω = Angular Velocity

* Note that the Moment of Inertia calculation
divided the post in two for simplicity.

$$I_{Cylinder} = \frac{mr^2}{4} + \frac{mL^2}{3}$$

$I_{Cylinder}$ = Moment of inertia of a solid cylinder about one end

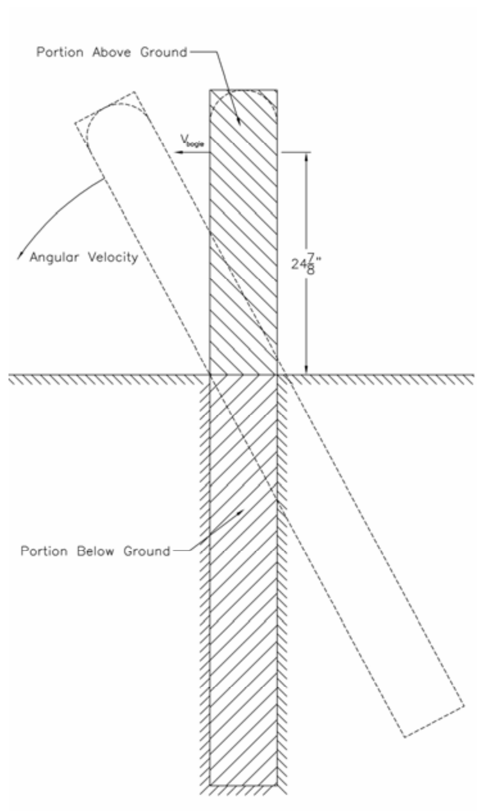
$$I_{Total} = I_1 + I_2$$

I_1 = Moment of inertia of the above ground portion

I_2 = Moment of inertia of the below ground portion

L = Length of the upper or lower portions of the post

r = Radius of the post



$$m_1 = \left(\frac{W}{32.174 \, ft/s^2} \right) \left(\frac{L_T - 40\,in.}{L_T} \right)$$

$$m_2 = \left(\frac{W}{32.174 \, ft/s^2} \right) \left(\frac{40\,in.}{L_T} \right)$$

W = Weight of the post

L_T = Total length of the post

$$H_G = I_{Total}\,\omega$$

H_G = Angular momentum of the post

$$M = \frac{H_G}{H_I}$$

M = Linear Momentum

$$I = \int F dt$$

F = Bogie force

I = Impulse

$$I = \Delta M = M_{Final} - M_{Initial} = M_{Final} = M$$

*Velocity of the post at MGS height just after impact was assumed to be equal to the initial velocity of the bogie. This assumption was supported by: (1) film analysis that showed no separation between the post and the impact head, and (2) no significant amount of bogie velocity reduction during the initial portion of the impact.

Table 22. Douglas Fir Impulse-Momentum Comparison

	Angular Momentum (H_G)		Linear Momentum (M)		*Impulse (I)		Ratio	Ratio
Test No.	J-s	(ft-lbs-sec)	N-sec	(lb-sec)	N-s	(lb-sec)	I / M	M / I
DF-1	166.11	(122.52)	262.90	(59.10)	289.45	(65.07)	1.10	0.91
DF-2	164.28	(121.17)	260.00	(58.45)	315.20	(70.86)	1.21	0.82
DF-3	135.86	(100.20)	215.02	(48.34)	285.30	(64.14)	1.33	0.75
DF-4	130.09	(95.95)	205.89	(46.29)	245.37	(55.16)	1.19	0.84
DF-5	145.72	(107.48)	230.62	(51.85)	288.07	(64.76)	1.25	0.80
DF-6	163.57	(120.64)	258.87	(58.20)	299.55	(67.34)	1.16	0.86
DF-7	153.41	(113.15)	242.79	(54.58)	277.71	(62.43)	1.14	0.87
DF-8	167.38	(123.45)	264.91	(59.55)	306.70	(68.95)	1.16	0.86
DF-9	149.39	(110.19)	236.43	(53.15)	281.27	(63.23)	1.19	0.84
DF-10	159.76	(117.83)	252.84	(56.84)	316.76	(71.21)	1.25	0.80
DF-11	131.68	(97.12)	208.40	(46.85)	240.61	(54.09)	1.15	0.87
DF-12	131.71	(97.14)	208.44	(46.86)	282.77	(63.57)	1.36	0.74
DF-13	163.20	(120.37)	258.28	(58.06)	323.82	(72.80)	1.25	0.80
DF-14	143.99	(106.20)	227.89	(51.23)	278.46	(62.60)	1.22	0.82
DF-15	138.10	(101.86)	218.56	(49.13)	254.83	(57.29)	1.17	0.86
Average	149.62	(110.35)	236.79	(53.23)	285.72	(64.23)	1.21	0.83

*Calculation based on ∫Fdt.

Table 23. Ponderosa Pine Impulse-Momentum Comparison

	Angular Momentum (H_G)		Linear Momentum (M)		*Impulse (I)		Ratio	Ratio
Test No.	J-s	(ft-lbs-sec)	N-sec	(lb-sec)	N-s	(lb-sec)	I / M	M / I
PP-1	247.02	(182.19)	390.94	(87.89)	325.64	(73.21)	0.83	1.20
PP-2	276.11	(203.65)	436.99	(98.24)	369.11	(82.98)	0.84	1.18
PP-3	281.85	(207.88)	446.08	(100.28)	432.56	(97.24)	0.97	1.03
PP-4	215.32	(158.81)	340.77	(76.61)	353.78	(79.53)	1.04	0.96
PP-5	194.30	(143.31)	307.51	(69.13)	306.66	(68.94)	1.00	1.00
PP-6	268.92	(198.34)	425.60	(95.68)	465.33	(104.61)	1.09	0.91
PP-7	281.15	(207.37)	444.97	(100.03)	425.69	(95.70)	0.96	1.05
PP-8	224.17	(165.34)	354.79	(79.76)	348.19	(78.28)	0.98	1.02
PP-9	247.21	(182.33)	391.25	(87.96)	374.23	(84.13)	0.96	1.05
PP-10	278.34	(205.29)	440.51	(99.03)	392.66	(88.27)	0.89	1.12
PP-11	331.15	(244.25)	524.10	(117.82)	472.98	(106.33)	0.90	1.11
PP-12	227.25	(167.61)	359.65	(80.85)	318.13	(71.52)	0.88	1.13
PP-13	290.09	(213.96)	459.12	(103.21)	417.85	(93.94)	0.91	1.10
PP-14	269.45	(198.73)	426.44	(95.87)	373.21	(83.90)	0.88	1.14
PP-15	233.09	(171.92)	368.90	(82.93)	380.34	(85.50)	1.03	0.97
Average	257.70	(190.07)	407.84	(91.69)	383.76	(86.27)	0.94	1.07

*Calculation based on ∫Fdt.

Table 24. Southern Yellow Pine Impulse-Momentum Comparison

	Angular Momentum (H_G)		Linear Momentum (M)		*Impulse (I)		Ratio	Ratio
Test No.	J-s	(ft-lbs-sec)	N-sec	(lb-sec)	N-s	(lb-sec)	I / M	M / I
SY-1	174.43	(128.65)	276.06	(62.06)	307.01	(69.02)	1.11	0.90
SY-2	151.58	(111.80)	239.89	(53.93)	221.13	(49.71)	0.92	1.08
SY-3	170.06	(125.43)	269.15	(60.51)	238.29	(53.57)	0.89	1.13
SY-4	144.59	(106.64)	228.83	(51.44)	249.89	(56.18)	1.09	0.92
SY-5	181.68	(134.00)	287.54	(64.64)	294.00	(66.09)	1.02	0.98
SY-6	189.49	(139.76)	299.89	(67.42)	290.26	(65.25)	0.97	1.03
SY-7	183.62	(135.43)	290.60	(65.33)	293.53	(65.99)	1.01	0.99
SY-8	175.17	(129.20)	277.23	(62.32)	271.42	(61.02)	0.98	1.02
SY-9	186.69	(137.70)	295.47	(66.42)	300.33	(67.52)	1.02	0.98
SY-10	181.63	(133.96)	287.46	(64.62)	265.29	(59.64)	0.92	1.08
SY-11	172.62	(127.32)	273.20	(61.42)	259.56	(58.35)	0.95	1.05
SY-12	158.93	(117.22)	251.54	(56.55)	243.57	(54.76)	0.97	1.03
SY-13	139.40	(102.81)	220.62	(49.60)	246.49	(55.41)	1.12	0.90
SY-14	185.79	(137.03)	294.04	(66.10)	272.03	(61.15)	0.93	1.08
SY-15	169.66	(125.14)	268.52	(60.37)	307.06	(69.03)	1.14	0.87
Average	171.02	(126.14)	270.67	(60.85)	270.66	(60.85)	1.00	1.00

*Calculation based on $\int F dt$.

The final piece of supporting evidence was a bogie test completed at MwRSF in December of 2004. The test was conducted in soil on a 1778 mm (70 in.) W6x16 steel post with a 1016 mm (40 in.) embedment depth. For the test, the post was cut into two pieces at 101.6 mm (4 in.) above the ground line and re-connected with a hinge on the back side. This allowed the post to rotate freely as it bent backwards. To measure the actual load in the post, a load cell was placed on the front side of the post, connecting the top and bottom sections. With the exception of the soil, the post was impacted using the same conditions as those used in the round post study. The data from the load cell was compared to that from the accelerometer, and the results are presented in Figure 40.

The graph clearly shows that the data from the accelerometer contained an initial spike that was not present in the data from the load cell. This suggested that there was indeed an additional force felt by the bogie that was not due to the bending of the post but rather due to the acceleration of the post and the soil. Although this test was completed in soil, it suggests that there is indeed an inertial spike at the front end of the accelerometer data.

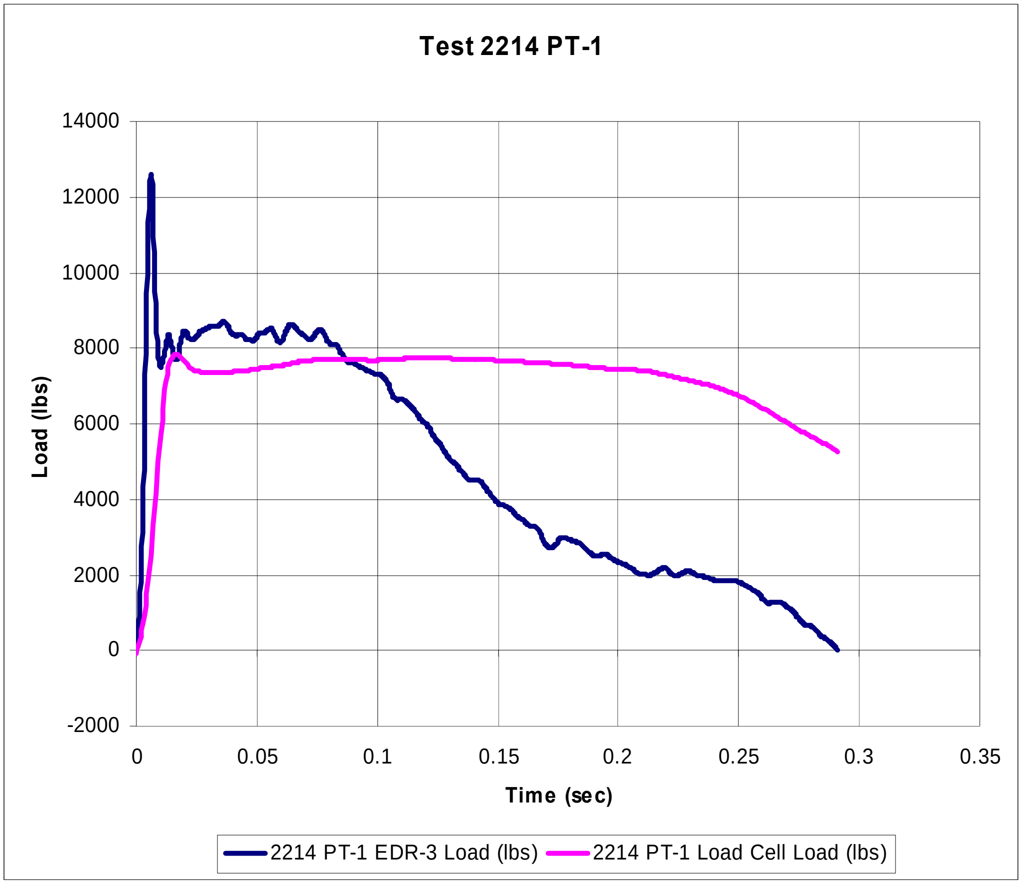


Figure 40. Bogie Force and Post Force Test PT-1

7.3.3 Distinction between Real and Inertial Forces

If the inertial spike theory is true, the inertial force and the real resistive force need to be separated to determine the actual strength of the posts. When the post tests were conducted with some amount of compliance in the sleeve, the inertial force was very distinct. However, the less compliance that exists, the more vague the distinction will become. For example, in a fully fixed test where the posts were embedded in concrete, the inertial and real forces would be combined into a single spike and distinguishing between the two would be impossible.

7.4 Effects of the Inertial Spike Theory

Consideration of the inertial spike theory may have a significant effect on some of the post tests while having little or no effect on others. In the cases in which the inertial spike was lower than a subsequent spike, very little change will occur. Several of these tests were filtered without the inertial spike, but only very slight changes were noted in the peak force levels.

For the cases in which the inertial spike was also the maximum spike, the theory may have significant effects. The first problem was that excluding the inertial spike severely reduced the calculated strength of the posts because the maximum force was significantly lowered. However, considering the inertial spike theory in more detail, the strength of the post may not be as low as this new analysis suggests.

If the bogie impacts a post and causes it to rotate, the fixed sleeve must eventually bring the base of the post to a stop, or it would never fracture. If the inertia of the post is great enough, the sleeve’s slowing force may cause bending in the post or even failure. If this occurs, the additional force from the bogie, required to fracture the post, may only be responsible for a small portion of the ultimate stress in the fibers since the two opposing forces act simultaneously. When this occurs, determining the force that was required to fracture the post is very difficult. In the other scenario, when the inertial force is great enough that the sleeve’s slowing force can fail the fibers by itself, the bogie may not even apply additional force to fracture the post. This potential scenario greatly complicates efforts to eliminate the effects of the inertial spike from the analysis.

Because the theory had a potentially significant effect on the future tests within the project, three additional bogie tests were conducted at half the impact speed to prove or disprove that inertia caused the initial spike in the dynamic data. If inertia did cause the initial spike, the impulse should also be cut in half because the momentum of the post was cut in half.

7.4.1 Predicted Impulse and Angular Momentum

Using the same procedures as before, the angular momentum, linear momentum, and impulse were predicted for the tests and are shown in Table 25. It was assumed that the impulse would be the same as the calculated momentum as it was for the previous Southern Yellow Pine post tests.

Table 25. Supplemental Bogie Testing Predictions

	Dry Weight	Wet Weight	Angular Momentum (H_G)		Linear Momentum (M)		Predicted Impulse (I)		Predicted Peak Force	Peak Force (Test Results)
Post No.	(lb)	(lb)	J-s	(ft-lbs-sec)	N-sec	(lb-sec)	N-s	(lb-sec)	(k)	(k)
SYPI-A	64	69	98.26	(72.47)	155.51	(34.96)	155.51	(34.96)	16.35	22.30
SYPI-B	75	80	86.31	(63.66)	136.59	(30.71)	136.59	(30.71)	14.36	20.20
SYPI-C	67	73	70.67	(52.12)	111.85	(25.14)	111.85	(25.14)	11.76	17.90

A significant assumption was made to calculate the peak force. This assumption was the duration of the impulse. If the duration of the impulse was the same as the previous tests at 32 km/hr (20 mph), the peak force would be half of what it was previously. If the duration of the impulse was twice the previous duration, the peak force would be a quarter of its previous value.

Based on prior experience, the duration of an impact is often fairly independent of the impact velocity. This meant that the duration of the impact event would be approximately the same as before, and for the purposes of the project, it will be assumed to be exactly the same. Therefore, an impulse duration of 0.003208 sec, which was the average duration for the previous tests, was chosen.

A semi-parabolic impulse spike approximation was used to calculate the peak force because it more closely approximated the physical test data than a triangular or parabolic distribution. The Impulse was approximated as:

$$I = \frac{2(\Delta t)(F_{Peak})}{3}$$

Rearranging the equation for peak load resulted in the expression shown below, which was then used to determine the force values for each post. These results are also shown in Table 25.

$$F_{Peak} = \frac{3(I)}{2(\Delta t)}$$

7.4.2 Supplemental Testing

Three supplemental bogie tests were conducted on round Southern Yellow Pine posts from the same lot as those tested previously. In this set of tests, the impact speed was reduced and all other factors were held consistent with the previous tests. Note that test no. SYPI-3 was conducted at 6.1 m/s (13.6 mph) rather than the anticipated 4.5 m/s (10 mph.).

When the tests were completed, the accelerometer data was analyzed and investigated as before. The test results for peak acceleration, peak force, impulse, linear momentum, as calculated previously, and impact speed are presented and compared to the previous tests in Table 26. Complete results for the three tests are provided in Appendix D, and a summary of the test results is provided in Table 27. A ratio of the results from the supplemental tests to the results from the original tests is also calculated to show its similarity to the ratio of the impact speeds.

Table 26. Supplemental Bogie Test Results Comparison

Test No.	Peak Acceleration (G's)	Peak Force (Kips)	Predicted Peak Force (Kips)	Impulse (I) (lb-sec)	Linear Momentum (M) (lb-sec)	Impact Speed (ft/s)
SYPI-1	11.17	17.92	11.76	31.35	25.14	14.67
SYPI-2	12.61	20.23	14.36	38.26	30.71	14.90
SYPI 1-2 Average	**11.89**	**19.08**	**13.06**	**34.81**	**27.93**	**14.78**
SY 1-15 Average	**19.99**	**32.08**		**60.85**	**60.85**	**29.00**
Ratio	**0.595**	**0.595**		**0.572**	**0.459**	**0.510**
SYPI-3	13.92	22.34	16.35	40.17	34.96	19.88
SY 1-15 Average	**19.99**	**32.08**		**60.85**	**60.85**	**29.00**
Ratio	**0.696**	**0.696**		**0.660**	**0.575**	**0.686**

The results shown in Table 26 were very close to those shown in Table 25, which were predicted by the inertial spike theory. For the first two supplemental tests, conducted at approximately 4.5 m/s (10.0 mph), the peak acceleration, peak force, and impulse of the initial acceleration spike should have been approximately half of the values determined for tests conducted at 8.9 m/s (20 mph). As shown in Table 26, the new values ranged from 57 percent to 60 percent of the old, very close to what was expected. The third test, conducted at approximately 5.8 m/s (13 mph), should have reached peak acceleration, peak force, and impulse values for the initial acceleration spike that were about 65 percent of the values determined for the previous tests. Again, the results support this with values ranging from 66 percent to 70 percent of the previous results. These comparisons offer significant support for the inertial spike theory.

A comparison of the acceleration vs. time plots is shown in Figure 41 and Figure 42. In test no. SY-3, shown in Figure 41, the initial spike of the filtered acceleration exceeded the second peak. However, when the velocity was decreased for test no. SYPI-

3, shown in Figure 42, the initial spike in the filtered data was just slightly over half of the second spike. Clearly, the impact velocity has a large effect on the magnitude of the initial filtered acceleration spike.

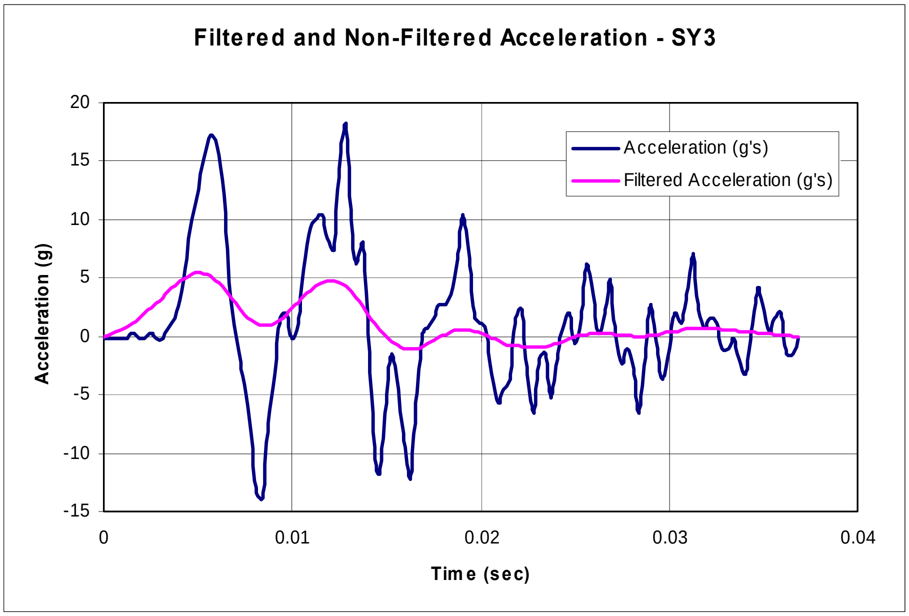


Figure 41. Acceleration vs. Time - Test No. SY-3

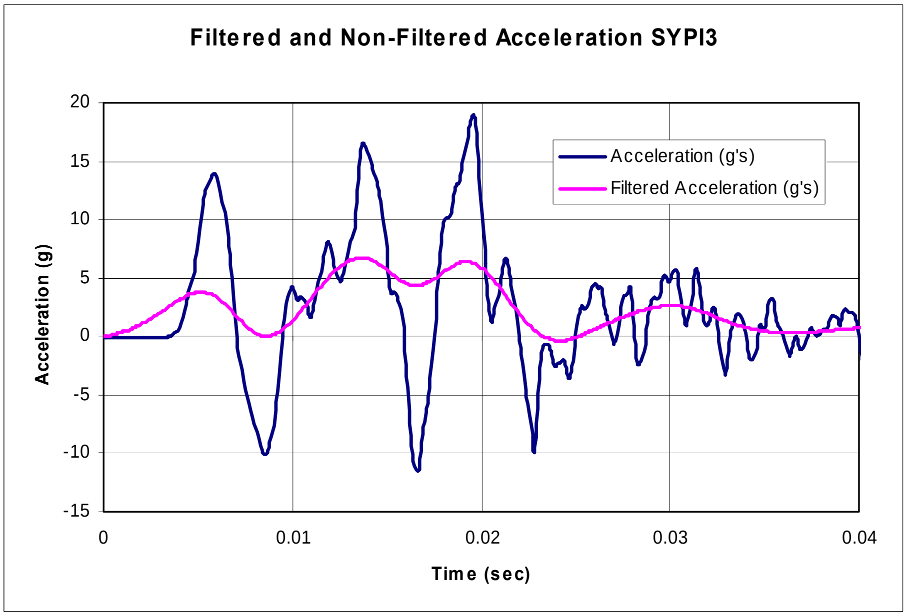


Figure 42. Acceleration vs. Time - Test No. SYPI-3

Table 27. Supplemental Bogie Test Results Summary

	Post Test No.	Post Number	Post Category	Ring Density	Average Diameter		Peak Force							Rupture						Moisture Content	Modulus of Rupture		Impact Velocity	
							Time	Force		Deflection		Energy		Time	Deflection		Energy							
				rings/in.	mm	(in.)	ms	kN	(kips)	mm	(in.)	kJ	(kip-in.)	ms	mm	(in.)	kJ	(kip-in.)	(%)	Mpa	($k/in.^2$)	m/s	(mph)
Inertial SYP	SYPI-1	C	NA	4.00	177	(6.9)	19.2	57.1	(12.8)	81	(3.2)	2.27	(20.1)	197.6	457	(18.0)	6.23	(55.4)	26	54.4	(7.89)	4.5	(10.0)
	SYPI-2	B	NA	10.33	186	(7.3)	26.2	63.9	(14.4)	106	(4.2)	3.87	(34.3)	155.9	216	(8.5)	7.50	(66.4)	22	70.2	(10.18)	4.5	(10.2)
	SYPI-3	A	NA	2.67	185	(7.3)	13.6	48.1	(10.8)	81	(3.2)	1.39	(12.3)	88.2	463	(18.2)	4.40	(39.0)	28	46.6	(6.75)	6.1	(13.6)
	Overall Average			**5.67**	**182**	**(7.2)**	**19.66667**	**56.3**	**(12.7)**	**89**	**(3.5)**	**2.51**	**(22.2)**	**147.2**	**378**	**(14.9)**	**6.05**	**(53.6)**	**25**	**57.05**	**(8.3)**	**5.0**	**(11.2)**
	Standard Deviation			**4.09**	**5.16**	**(0.2)**	**6.31295**	**7.9**	**(1.8)**	**15**	**(0.6)**	**1.26**	**(11.2)**	**55.2**	**141**	**(5.5)**	**1.56**	**(13.8)**	**3**	**12.05**	**(1.7)**	**0.9**	**(2.0)**

***Data Filtered According to SAE J211/1 Requirements**

Limited by Maximum Deflection Criterion (20 in.)

Limited by Time of Contact

*Peak forces included in Table 27 are filtered as previous test results, and therefore differ from those shown in Table 25 and Table 26 , which are unfiltered.

7.4.3 Effects of Inertial Spike on Post Size

The cases in which the inertial spike was not the maximum overall force will have no effect on the post size determination. However, for the other cases, the MOR for the individual tests would decrease, reducing the overall average MOR for the species. This in turn would increase the recommended diameter for the posts. Unfortunately, the second set of posts was ordered before the inertial effects were fully investigated. Therefore, no diameter modification could be made prior to the second round of testing.

Instead, some modifications were made to the impact conditions. As shown in tests SYPI 1 through 3, the initial spike could be significantly reduced by lowering the impact velocity of the bogie. In fact, if the velocity of the bogie was halved, the initial impulse should also be halved. Although the modification will not eliminate the inertia problem, it will significantly reduce it and should help in determining the actual fracturing force for each post.

7.4.4 Effects on Future Testing

In future tests, similar adjustments should be made. Although changing the restraint conditions would also modify the results, the alteration could make the peak force determination more difficult as alluded to previously. Therefore, the only change that is suggested is the reduction of the impact speed.

The new theory offers further understanding into the physics of cantilever post impacts and will likely help fine tune bogie testing procedures used in the future. Clearly the historic methods of testing cannot produce accurate results and should be abandoned.

8 PHYSICAL TESTING – ROUND TWO

8.1 Purpose

After determining that the original post diameter chosen for each of the species was too large, an additional 15 dynamic bogie tests of each species were conducted on posts of the smaller diameters determined in Chapter 6. Again, the posts were divided into three categories, knots, baseline, and high ring density, and again the purpose of the testing was to evaluate the strength of the posts in bending.

8.2 Pretest Documentation and Preparation

Prior to post testing, the samples were extensively documented using all of the same techniques that were used in the first round. In addition, the critical region for each of the posts was painted white. This painted region greatly increased the visibility of the post fracture because it caused the cracks in the surface to appear very dark against the white background. The test documentation summaries are presented below in Table 28 and Table 29. Tables containing knot locations and sizes are presented in Appendix A. In addition, the posts were soaked in tanks of water to increase the moisture content as in the first round of testing. Table 30 and Table 31 show the recorded test day values for moisture content, weight, and base circumference.

Table 28. Ponderosa Pine Round Two Pre-Test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume (in.^{3})	Density (lb/in.^{3})	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Ponderosa Pine	502	58	78.125	22.208	22.625	22.875	3105	0.0187	15	17	17	5.67
	505	59	78.042	22.458	21.250	24.500	3167	0.0186	15	17	15	6.33
	506	48	78.083	22.208	22.750	25.125	3201	0.0150	17	15	17	4.67
	508	55	78.000	22.667	22.000	25.000	3263	0.0169	10	9	10	4.33
	510	53	78.000	20.083	20.750	21.625	2586	0.0205	14	13	12	3.33
	515	48	78.042	19.917	20.500	22.000	2557	0.0188	36	30	44	5.33
	516	47	78.000	20.833	22.000	21.750	2769	0.0170	17	16	17	7.00
	517	45	77.958	21.583	21.250	21.500	2875	0.0157	13	13	13	5.33
	518	57	78.125	21.208	21.750	22.250	2852	0.0200	30	31	27	6.67
	519	43	78.167	20.250	19.500	20.750	2537	0.0169	14	15	19	7.67
	521	66	78.042	23.833	24.000	24.500	3563	0.0185	14	14	15	15.00
	526	54	78.125	23.708	23.875	24.000	3511	0.0154	16	16	17	19.33
	527	56	78.083	22.375	22.250	23.750	3157	0.0177	18	16	22	13.33
	528	67	78.125	23.292	23.375	23.875	3393	0.0197	11	13	11	26.33
	530	73	78.146	23.083	23.625	24.000	3367	0.0217	33	43	31	15.00

Table 29. Douglas Fir Round Two Pre-Test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume ($in.^3$)	Density ($lb/in.^3$)	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Douglas Fir	401	63	78.125	19.917	19.125	20.500	2458	0.0256	65	58	71	3.67
	403	55	78.188	22.542	21.250	24.000	3165	0.0174	67	65	63	4.33
	404	78	78.167	22.083	20.000	22.500	2971	0.0263	53	49	39	4.33
	405	63	78.125	21.375	20.500	22.625	2852	0.0221	65	67	71	4.00
	410	59	78.167	22.292	21.750	23.125	3097	0.0191	66	65	69	3.67
	414	52	78.125	21.625	20.750	22.250	2894	0.0180	47	56	51	4.00
	415	59	78.146	21.792	20.750	22.625	2943	0.0200	74	71	74	3.67
	417	58	78.083	20.750	20.875	23.125	2764	0.0210	60	63	61	3.67
	418	65	78.125	23.083	22.250	24.125	3319	0.0196	22	30	29	5.67
	419	65	78.167	22.208	21.500	22.875	3062	0.0212	32	48	48	5.67
	421	68	78.146	21.917	21.625	22.375	2988	0.0228	60	66	63	12.33
	422	71	78.125	21.458	20.500	20.750	2799	0.0254	21	21	22	7.67
	425	62	78.167	21.083	20.500	21.250	2745	0.0226	36	32	26	9.33
	426	63	78.125	22.042	22.000	22.625	3036	0.0207	67	65	70	8.33
	429	69	78.125	22.792	22.625	23.250	3238	0.0213	59	39	70	5.67

Table 30. Ponderosa Pine Round Two Test Day Measurements

Test No.	Post No.	Weight (lbs)	Moisture Content (%) 21 in. from Top	Moisture Content (%) Center	Moisture Content (%) 21 in. from Bottom	Circumference at Bottom (in.)
PP-16	502	66	15	15	42	23 1/4
PP-17	505	69	14	29	48	24 7/8
PP-18	506	63	15	26	46	25 1/2
PP-19	508	68	16	23	48	25 1/4
PP-20	510	55	15	45	48	22
PP-21	515	54	14	44	46	22 1/4
PP-22	516	52	15	15	49	22 1/2
PP-23	517	51	13	15	46	22 1/4
PP-24	518	62	18	25	34	22 1/4
PP-25	519	46	14	16	38	21
PP-26	521	77	11	21	40	25 1/8
PP-27	526	71	19	34	46	24 1/2
PP-28	527	77	58	64	58	23 7/8
PP-29	528	75	17	41	39	24 1/4
PP-30	530	87	34	46	43	24

Table 31. Douglas Fir Round Two Test Day Measurements

Test No.	Post No.	Weight (lbs)	Moisture Content (%) 21 in. from Top	Moisture Content (%) Center	Moisture Content (%) 21 in. from Bottom	Circumference at Bottom (in.)
DF-16	401	59	25	58	70	22 1/8
DF-17	403	56	23	59	61	23 7/8
DF-18	404	79	30	45	54	22 3/4
DF-19	405	59	28	46	70	22 1/2
DF-20	410	60	21	35	66	23 1/4
DF-21	414	51	23	41	65	22 1/2
DF-22	415	60	49	59	72	22 3/4
DF-23	417	59	52	62	64	23 1/4
DF-24	418	69	21	46	61	24 1/2
DF-25	419	64	23	66	63	23 1/8
DF-26	421	64	21	67	60	22 3/8
DF-27	422	68	19	51	60	23 1/4
DF-28	425	65	20	27	63	21 1/2
DF-29	426	62	19	29	71	22 3/4
DF-30	429	69	25	54	59	23 3/8

8.3 Scope

The second series of bogie tests was conducted with the round posts installed in a rigid steel sleeve that was embedded in concrete. Fifteen tests were conducted for each species with a centerline impact at approximately 13 mph, 632 mm (24.875 in.) above the ground. The speed was reduced from the first round of testing in order to reduce the inertial spike discussed previously. Also in the second round of tests, the posts were arranged so the most knotty face was oriented toward the impacting bogie (i.e., placing the critical knots in the tension face). This arrangement was not followed in the first round of tests. The testing matrix for the second round of tests is shown in Figure 43 below. The test setup is identical to the previous setup.

Test No.	Post No.	Wooden Post Type	Post Length (in.)	Post Diameter (in.)
DF-16	401	Douglas Fir	78.1	6.34
DF-17	403	Douglas Fir	78.2	7.18
DF-18	404	Douglas Fir	78.2	7.03
DF-19	405	Douglas Fir	78.1	6.80
DF-20	410	Douglas Fir	78.2	7.10
DF-21	414	Douglas Fir	78.1	7.88
DF-22	415	Douglas Fir	78.1	6.94
DF-23	417	Douglas Fir	78.1	6.60
DF-24	418	Douglas Fir	78.1	7.35
DF-25	419	Douglas Fir	78.2	7.07
DF-26	421	Douglas Fir	78.1	6.98
DF-27	422	Douglas Fir	78.1	6.83
DF-28	425	Douglas Fir	78.2	6.71
DF-29	426	Douglas Fir	78.1	7.02
DF-30	429	Douglas Fir	78.1	7.25
PP-16	502	Ponderosa Pine	78.1	7.07
PP-17	505	Ponderosa Pine	78.0	7.15
PP-18	506	Ponderosa Pine	78.1	7.07
PP-19	508	Ponderosa Pine	78.0	7.22
PP-20	510	Ponderosa Pine	78.0	6.39
PP-21	515	Ponderosa Pine	78.0	6.34
PP-22	516	Ponderosa Pine	78.0	6.63
PP-23	517	Ponderosa Pine	78.0	6.87
PP-24	518	Ponderosa Pine	78.1	6.75
PP-25	519	Ponderosa Pine	78.2	6.45
PP-26	521	Ponderosa Pine	78.0	7.59
PP-27	526	Ponderosa Pine	78.1	7.55
PP-28	527	Ponderosa Pine	78.1	7.12
PP-29	528	Ponderosa Pine	78.1	7.41
PP-30	530	Ponderosa Pine	78.1	7.35

NOTES:

(1) TARGET SPEED = 13 MPH (NOT LOWER)

(2) IMPACT ORIENTATION: CENTERLINE OF POST (W/ARROW POINTING TOWARD BOGIE) AND CENTERLINE OF BOGIE

Midwest Roadside Safety Facility

FOREST PRODUCTS LAB
ROUND POST TESTING
ROUND TWO BOGIE SETUP

TEST MATRIX

Sheet: 4 of 4
Date: 7/27/05
By: JAH
Rev: KAP
Drawing Name: FPL Bogie Testing Matrix
Scale: None

Figure 43. Round Two Bogie Testing Matrix

9 SYSTEM DETAILS – ROUND TWO

9.1 Round Wood Posts

All of the round post samples were again donated by companies in the forestry industry. The Ponderosa Pine samples were donated by Hill Products Group, and the Douglas Fir samples were donated by All-Weather Wood Products.

The nominal length of the posts was again 1,905 mm (78 in.). The nominal target diameter of the posts was 171 mm (6.75 in.) for Douglas Fir and 191 mm (7.5 in.) for Ponderosa Pine. Figure 44 shows the dimensions for each of the selected posts.

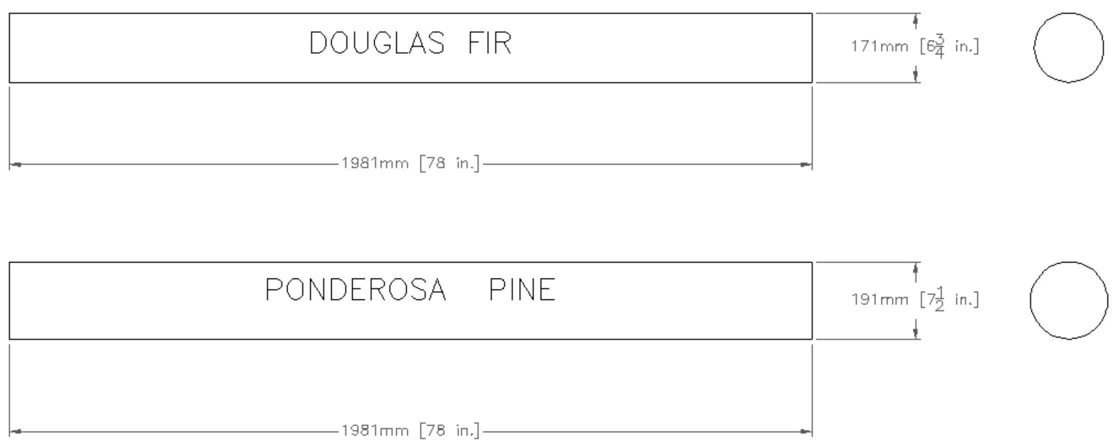


Figure 44. Major Dimensions of Round Wood Posts - Round Two Testing

9.2 Equipment and Instrumentation

The equipment and instrumentation used in the second round of tests was largely the same as that used in the first round. The only exception was the use of two additional high-speed digital video cameras. During the second round of tests, one high-speed Photron digital video camera and two high-speed VITcam digital video cameras, all with speeds of 500 frames per second, were used to record the events. One of the high-speed cameras was focused on the base of the post, clearly displaying the fracture as it occurred. A second camera was focused on the impact location, which was used to investigate any interaction between the bogie impact head and the posts.

As in the previous round of testing, the cameras were placed approximately 25 ft from the centerline of the posts, with a field of view perpendicular to the bogie's direction of travel. When needed, flood lights were used to light the base of the posts. The recorded acceleration data was processed in the same manner as that recorded in the first round of bogie tests. The end of the test was also determined in the same manner as before.

10 ROUND 2 CANTILEVER TEST RESULTS

Bogie vehicle acceleration traces were processed for each of the tests in order to determine acceleration, velocity, and displacement curves, as well as force-deflection curves using the procedure described previously. Results for individual tests can be found in Appendix E, and test results and summary data can be found in Table 32 and Table 33 for Ponderosa Pine and Douglas Fir, respectively.

10.1 MOR Results

Similar to the first round of tests, an MOR value was calculated for each of the 45 tests and is shown in the mentioned tables. The highest average MOR was 57 MPa (8.3 ksi) for the Douglas Fir posts, and the lowest average MOR was 49 MPa (7.2 ksi) for the Ponderosa Pine posts. The average MOR values were very similar to those from the previous round of testing, with the average for Ponderosa Pine increasing by 1 percent, and that for Douglas Fir decreasing by 3 percent.

10.1.1 Ponderosa Pine

Ponderosa Pine had an average MOR of 49 MPa (7.2 ksi). The knots category showed an MOR of 46 MPa (6.7 ksi), a 2 percent increase, the baseline category showed an MOR of 50 MPa (7.3 ksi), a 29 percent increase, and the HRD category showed an MOR of 52 MPa (7.6 ksi), an 18 percent decrease. The highest MOR was 71.0 MPa (10.30 ksi) for test PP-26 in the HRD category, and the lowest was 31.9 MPa (4.62 ksi) for test PP-19 in the knots category. Clearly, there was a significant difference between the two extremes. In addition to the presence of knots, a likely explanation was the difference in ring density from 15.0 rings-per-inch for PP-26 to 4.33 rings-per-inch for PP-19.

10.1.2 Douglas Fir

The Douglas Fir tests showed an overall decrease in MOR of 3 percent. This drop corresponded to an average MOR value of 57 MPa (8.3 ksi). The lowest average MOR for the individual categories was 49 MPa (7.2 ksi) for the knots category, a 16 percent decrease from the previous round of tests, and the highest was 69 MPa (10 ksi) for the HRD category, a 6 percent increase. The baseline category fell in the middle with an average MOR of 53 MPa (7.6 ksi), a 1 percent increase from the previous testing. The highest MOR for an individual test was 77 MPa (11 ksi) for test DF-28 in the HRD category, and the lowest MOR was 26 MPa (3.7 ksi) for test DF-17 in the knots category. Again the difference could be attributed to the presence of knots and a decreased ring density of 4.33 rings-per-inch for DF-17 as compared to 9.33 rings-per-inch for DF-28.

The differences in the average MOR between the two rounds of testing have significant effects on the suggested diameter for both species. For instance, the 6 percent increase noticed in the Douglas Fir HRD category would constitute a 3-mm (0.125-in.) decrease in diameter. As this percentage increases, it begins to make significant differences in the amount of material in a post. Placing the knots in the tension face clearly lowered the MOR for the knots category, which may have significant effects on the final size of the posts. Orienting the knots may not have been completely warranted since posts installed in the field will be placed randomly rather than in the worst-case orientation.

10.2 Force Results

As with the previous testing, it was important for the posts to have sufficient strength to be able to rotate in the soil rather than fracture. Therefore, the peak force that a post can resist was a very important factor. The difficulty in comparing peak forces was that the posts were of different sizes. Although all of the posts of a given species were intended to be the same size, there was a significant variation caused by the processing. This variation is considerably larger in the second round of tests than in the first round. It should also be noted that the actual average diameter was not as accurate in the second round as it was in the first. For instance, the nominal suggested diameter of the Ponderosa Pine samples was 191 mm (7.5 in.), yet the actual average diameter was only 178 mm (7.0 in.). Therefore, using the peak force as an indicator of the strength of the posts was difficult because, for a given wood strength, a 178 mm (7.0 in.) diameter post would have a 23 percent lower fracture force than a 191 mm (7.5 in.) diameter post.

10.2.1 Ponderosa Pine

For Ponderosa Pine, the overall average peak force was 43.6 kN (9.8 kips). The standard deviation for this value was 13.1 kN (3.0 kips). Once again, the three categories demonstrated very different force levels. The average peak force for the knots category was 39.2 kN (8.8 kips), the average peak force for the baseline category was 37.1 kN (8.3 kips), and the average peak force for the HRD category was 54.5 kN (12.3 kips). Test PP-26, of the HRD category, had the highest peak force at 79.0 kN (17.8 kips). Test PP-19, of the knots category, resulted in the lowest peak force of 30.5 kN (6.9 kips), which is less than 1 standard deviation from the mean. This implies that the data is not perfectly normally distributed, but rather right-skewed, and is probably due to the very small sample size.

Contrary to what may be expected, the knots category did not demonstrate the lowest average force value, but rather the baseline category. This can be explained by the size of the posts and the MOR. As shown in Section 11.1.2, the MOR for the baseline category was higher than that for the knots category. However, in the knots category, the average diameter was 177 mm (7.0 in.), while the average diameter for the baseline category was only 168 mm (6.6 in.). This makes the average force from the knots category higher than that of the baseline category.

10.2.2 Douglas Fir

Lastly, the Douglas Fir posts resulted in the highest overall average peak force of 48.5 kN (10.9 kips) with a standard deviation of 12.2 kN (2.7 kips). The highest individual peak force was found in the baseline category from test DF-24, which was 60.5 kN (13.6 kips). The lowest individual peak force was 23.9 kN (5.4 kips) found in test DF-17 of the knots category. The knots category had the lowest average peak force with 40.7 kN (9.2 kips), the baseline category was in the middle with 45.6 kN (10.3 kips), and the HRD category resulted in the highest average peak force with 59.1 kN (13.3 kips).

The average peak force values for Douglas Fir followed the pattern that was expected, with average peak force increasing from knots to baseline to HRD. In the case of Douglas Fir, the diameters of the posts were much more consistent. The knots category averaged 175 mm (6.9 in.) and the baseline and HRD categories both averaged 177 mm (7.0 in.). This result would further support the ranking of peak force from knots to baseline to HRD.

Table 32. Ponderosa Pine Round Wood Post Test Results - Round Two Testing

	Post Test No.	Post No.	Category	Ring Density	Average Diameter		Peak Force							Rupture						Moisture Content	Modulus of Rupture		Impact Velocity	
							Time	Force		Deflection		Energy		Time	Deflection		Energy							
				rings/in.	mm	(in.)	ms	kN	(kips)	mm	(in.)	kJ	(kip-in.)	ms	mm	(in.)	kJ	(kip-in.)	(%)	Mpa	(k/in.^{2})	m/s	(mph)
Ponderosa Pine	PP-16	502	KNOTS	5.67	179	(7.1)	15.0	41.6	(9.3)	82	(3.2)	1.20	(10.6)	56.6	291	(11.5)	2.78	(24.6)	42	46.2	(6.70)	6.2	(13.8)
	PP-17	505		6.33	181	(7.1)	14.1	44.9	(10.1)	80	(3.2)	1.21	(10.7)	22.5	126	(5.0)	1.63	(14.4)	48	48.2	(7.00)	6.1	(13.5)
	PP-18	506		4.67	179	(7.1)	15.0	41.7	(9.4)	92	(3.6)	1.32	(11.7)	22.8	137	(5.4)	1.74	(15.4)	46	46.4	(6.73)	5.9	(13.2)
	PP-19	508		4.33	183	(7.2)	13.4	30.5	(6.9)	81	(3.2)	1.06	(9.4)	22.5	134	(5.3)	1.36	(12.0)	48	31.9	(4.62)	5.9	(13.2)
	PP-20	510		3.33	162	(6.4)	25.0	37.6	(8.5)	153	(6.0)	1.26	(11.1)	33.1	200	(7.9)	1.70	(15.0)	48	56.5	(8.20)	6.1	(13.6)
	KNOTS Average			4.87	177	(7.0)	16.5	39.2	(8.8)	97	(3.8)	1.21	(10.7)	31.5	178	(7.0)	1.84	(16.3)	46	45.8	(6.65)	6.0	(13.5)
	PP-21	515	BASELINE	5.33	161	(6.3)	15.9	31.6	(7.1)	97	(3.8)	1.12	(9.9)	89.7	510	(20.1)	3.35	(29.7)	46	48.6	(7.05)	6.1	(13.8)
	PP-22	516		7.00	168	(6.6)	13.8	42.6	(9.6)	86	(3.4)	1.22	(10.8)	26.3	159	(6.3)	2.33	(20.6)	49	57.3	(8.31)	5.9	(13.3)
	PP-23	517		5.33	174	(6.9)	15.6	32.5	(7.3)	94	(3.7)	1.12	(9.9)	45.6	266	(10.5)	2.12	(18.8)	46	39.4	(5.71)	6.3	(14.1)
	PP-24	518		6.67	171	(6.8)	15.9	46.1	(10.4)	100	(3.9)	1.65	(14.6)	88.4	508	(20.0)	3.73	(33.0)	34	58.8	(8.53)	6.4	(14.3)
	PP-25	519		7.67	164	(6.4)	13.8	32.8	(7.4)	87	(3.4)	1.03	(9.1)	55.3	327	(12.9)	3.87	(34.3)	38	48.1	(6.98)	5.8	(13.0)
	BASELINE Average			6.40	168	(6.6)	15.0	37.1	(8.3)	93	(3.7)	1.23	(10.9)	61.1	354	(13.9)	3.08	(27.3)	43	50.4	(7.32)	6.1	(13.7)
	PP-26	521	HRD	15.00	193	(7.6)	20.6	79.0	(17.8)	122	(4.8)	4.50	(39.8)	75.9	384	(15.1)	6.66	(59.0)	40	71.0	(10.30)	6.1	(13.7)
	PP-27	526		19.33	192	(7.5)	20.9	65.1	(14.6)	116	(4.6)	2.85	(25.2)	55.3	278	(10.9)	4.46	(39.5)	46	59.5	(8.63)	6.2	(13.9)
	PP-28	527		13.33	181	(7.1)	15.3	40.3	(9.1)	93	(3.7)	1.51	(13.4)	89.7	493	(19.4)	4.18	(37.0)	58	43.8	(6.36)	6.2	(14.0)
	PP-29	528		26.33	188	(7.4)	20.0	50.3	(11.3)	114	(4.5)	3.24	(28.7)	122.8	508	(20.0)	9.85	(87.2)	39	48.5	(7.03)	6.2	(14.0)
	PP-30	530		15.00	186	(7.3)	15.3	37.9	(8.5)	92	(3.6)	1.47	(13.0)	50.0	282	(11.1)	3.43	(30.3)	43	37.6	(5.45)	5.9	(13.2)
	HRD Average			17.80	188	(7.4)	18.4	54.5	(12.3)	108	(4.2)	2.72	(24.0)	78.7	389	(15.3)	5.72	(50.6)	45	52.1	(7.55)	6.1	(13.7)
	Avg.			**9.69**	**178**	**(7.0)**	**16.6**	**43.6**	**(9.8)**	**99**	**(3.9)**	**1.72**	**(15.2)**	**57.1**	**307**	**(12.1)**	**3.55**	**(31.4)**	**45**	**49.46**	**(7.2)**	**6.1**	**(13.6)**
	St. Dev.			**6.65**	**10.4**	**(0.4)**	**3.4**	**13.1**	**(3.0)**	**20**	**(0.8)**	**1.01**	**(8.9)**	**30.5**	**144**	**(5.7)**	**2.24**	**(19.8)**	**6**	**9.91**	**(1.4)**	**0.2**	**(0.4)**

***Data Filtered According to SAE J211/1 Requirements**

Limited by Maximum Deflection Criterion (20 in.)

Limited by Time of Contact

Table 33. Douglas Fir Round Wood Post Test Results - Round Two Testing

	Post Test No.	Post No.	Category	Ring Density	Average Diameter		Peak Force Time	Peak Force Force		Peak Force Deflection		Peak Force Energy		Rupture Time	Rupture Deflection		Rupture Energy		Moisture Content	Modulus of Rupture		Impact Velocity	
				rings/in.	mm	(in.)	ms	kN	(kips)	mm	(in.)	kJ	(kip-in.)	ms	mm	(in.)	kJ	(kip-in.)	(%)	Mpa	(k/in.^{2})	m/s	(mph)
Douglas Fir	DF-16	401	KNOTS	3.67	161	(6.3)	12.2	38.9	(8.8)	74	(2.9)	1.20	(10.6)	90.9	510	(20.1)	3.52	(31.2)	70	60.0	(8.70)	6.2	(13.8)
	DF-17	403	KNOTS	4.33	182	(7.2)	13.1	23.9	(5.4)	78	(3.1)	0.99	(8.8)	52.2	302	(11.9)	1.45	(12.8)	61	25.5	(3.69)	6.1	(13.5)
	DF-18	404	KNOTS	4.33	178	(7.0)	14.4	58.4	(13.1)	83	(3.3)	1.93	(17.1)	105.3	509	(20.0)	5.80	(51.3)	54	66.1	(9.58)	5.9	(13.2)
	DF-19	405	KNOTS	4.00	173	(6.8)	14.4	45.4	(10.2)	83	(3.3)	1.44	(12.7)	68.4	371	(14.6)	2.78	(24.6)	70	56.5	(8.20)	5.9	(13.2)
	DF-20	410	KNOTS	3.67	180	(7.1)	12.5	37.1	(8.3)	74	(2.9)	1.26	(11.1)	65.6	368	(14.5)	2.59	(22.9)	66	40.8	(5.91)	6.1	(13.6)
	KNOTS Average			4.00	175	(6.9)	13.3	40.7	(9.2)	78	(3.1)	1.36	(12.1)	76.5	412	(16.2)	3.23	(28.6)	64	49.8	(7.22)	6.0	(13.5)
	DF-21	414	BASELINE	4.00	175	(6.9)	12.5	40.8	(9.2)	75	(3.0)	1.39	(12.3)	56.3	323	(12.7)	2.29	(20.2)	65	49.1	(7.12)	6.1	(13.8)
	DF-22	415	BASELINE	3.67	176	(6.9)	13.8	31.5	(7.1)	80	(3.1)	1.17	(10.4)	43.8	247	(9.7)	1.78	(15.7)	72	37.1	(5.38)	5.9	(13.3)
	DF-23	417	BASELINE	3.67	168	(6.6)	12.2	40.6	(9.1)	75	(3.0)	1.46	(12.9)	54.4	322	(12.7)	2.30	(20.4)	64	55.3	(8.02)	6.3	(14.1)
	DF-24	418	BASELINE	5.67	186	(7.3)	14.1	60.5	(13.6)	88	(3.5)	2.02	(17.8)	90.6	510	(20.1)	4.66	(41.2)	61	59.9	(8.68)	6.4	(14.3)
	DF-25	419	BASELINE	5.67	179	(7.1)	13.8	54.8	(12.3)	78	(3.1)	1.54	(13.6)	101.6	509	(20.0)	4.01	(35.5)	63	60.9	(8.83)	5.8	(13.0)
	BASELINE Average			4.53	177	(7.0)	13.3	45.6	(10.3)	79	(3.1)	1.52	(13.4)	69.3	382	(15.0)	3.01	(26.6)	65	52.5	(7.61)	6.1	(13.7)
	DF-26	421	HRD	12.33	177	(7.0)	20.3	60.4	(13.6)	118	(4.6)	3.66	(32.4)	63.1	319	(12.6)	6.11	(54.1)	60	69.8	(10.13)	6.1	(13.7)
	DF-27	422	HRD	7.67	173	(6.8)	20.6	59.3	(13.3)	121	(4.8)	3.79	(33.6)	184.1	508	(20.0)	13.74	(121.6)	60	73.1	(10.60)	6.2	(13.9)
	DF-28	425	HRD	9.33	170	(6.7)	13.4	59.1	(13.3)	82	(3.2)	1.85	(16.4)	110.3	509	(20.0)	8.39	(74.2)	63	76.8	(11.13)	6.2	(14.0)
	DF-29	426	HRD	8.33	178	(7.0)	21.6	58.2	(13.1)	128	(5.1)	3.71	(32.8)	68.7	365	(14.4)	5.47	(48.4)	71	66.2	(9.60)	6.2	(14.0)
	DF-30	429	HRD	5.67	184	(7.3)	14.7	58.6	(13.2)	85	(3.3)	1.67	(14.8)	104.1	509	(20.0)	5.24	(46.4)	59	60.3	(8.75)	5.9	(13.2)
	HRD Average			8.67	177	(7.0)	18.1	59.1	(13.3)	107	(4.2)	2.94	(26.0)	106.1	442	(17.4)	7.79	(68.9)	63	69.2	(10.04)	6.1	(13.7)
	Avg.			**5.73**	**176**	**(6.9)**	**14.9**	**48.5**	**(10.9)**	**88**	**(3.5)**	**1.94**	**(17.2)**	**84.0**	**412**	**(16.2)**	**4.67**	**(41.4)**	**64**	**57.15**	**(8.3)**	**6.1**	**(13.6)**
	St. Dev.			**2.59**	**6.56**	**(0.3)**	**3.2**	**12.2**	**(2.7)**	**18**	**(0.7)**	**0.97**	**(8.6)**	**35.3**	**99**	**(3.9)**	**3.16**	**(28.0)**	**5**	**13.99**	**(2.0)**	**0.2**	**(0.4)**

***Data Filtered According to SAE J211/1 Requirements**

Limited by Maximum Deflection Criterion (20 in.)

Limited by Time of Contact

10.3 Adjusted Peak Force

As noted in the Section 10.2, it was difficult to compare peak forces for posts that varied in size. As such, an adjusted peak force was calculated based on a post's MOR and nominal diameter. This adjusted peak force was simply a prediction of the peak force for the specified diameter that could be used to make comparisons between individual categories and individual posts.

To calculate such a predicted force, the method presented in Chapter 6 was used. Once again, this assumed a linear stress distribution and standard elastic bending theory. The adjusted force values were calculated for each of the posts at their nominal size for round 2 and are shown in Table 34 and Table 35 below.

Table 34. Ponderosa Pine – Adjusted Peak Force

	Post Test No.	Post Number	Post Category	7.5 in. Diameter Adjusted Peak Force kN	(kips)
Ponderosa Pine	PP-16	502	KNOTS	49.6	(11.16)
	PP-17	505	KNOTS	51.8	(11.65)
	PP-18	506	KNOTS	49.8	(11.20)
	PP-19	508	KNOTS	34.2	(7.69)
	PP-20	510	KNOTS	60.7	(13.65)
	KNOTS Average			49.2	(11.07)
	PP-21	515	BASELINE	52.2	(11.74)
	PP-22	516	BASELINE	61.6	(13.84)
	PP-23	517	BASELINE	42.3	(9.51)
	PP-24	518	BASELINE	63.2	(14.20)
	PP-25	519	BASELINE	51.7	(11.62)
	BASELINE Average			54.2	(12.18)
	PP-26	521	HRD	76.3	(17.16)
	PP-27	526	HRD	63.9	(14.36)
	PP-28	527	HRD	47.1	(10.58)
	PP-29	528	HRD	52.1	(11.71)
	PP-30	530	HRD	40.3	(9.07)
	HRD Average			55.9	(12.58)
	Avg.			**53.13**	**(11.9)**
	St. Dev.			**10.65**	**(2.4)**

Table 35. Douglas Fir - Adjusted Peak Force

	Post Test No.	Post Number	Post Category	6.75 in. Diameter Adjusted Peak Force kN	(kips)
Douglas Fir	DF-16	401	KNOTS	47.0	(10.56)
	DF-17	403	KNOTS	19.9	(4.48)
	DF-18	404	KNOTS	51.7	(11.63)
	DF-19	405	KNOTS	44.3	(9.96)
	DF-20	410	KNOTS	31.9	(7.18)
	KNOTS Average			39.0	(8.76)
	DF-21	414	BASELINE	38.5	(8.65)
	DF-22	415	BASELINE	29.1	(6.53)
	DF-23	417	BASELINE	43.3	(9.73)
	DF-24	418	BASELINE	46.9	(10.54)
	DF-25	419	BASELINE	47.7	(10.72)
	BASELINE Average			41.1	(9.23)
	DF-26	421	HRD	54.7	(12.29)
	DF-27	422	HRD	57.2	(12.86)
	DF-28	425	HRD	60.1	(13.51)
	DF-29	426	HRD	51.8	(11.65)
	DF-30	429	HRD	47.2	(10.62)
	HRD Average			54.2	(12.19)
	Avg.			**44.75**	**(10.1)**
	St. Dev.			**10.96**	**(2.5)**

10.3.1 Ponderosa Pine

Adjusted peak forces for the Ponderosa Pine tests are shown in Table 34. As anticipated, for this species, the category trend is shown with knots as the weakest and high ring density as the strongest.

10.3.2 Douglas Fir

The adjusted peak forces for the Douglas Fir tests are shown in Table 35. Once again, the trend continued with the knots category being the weakest and the high ring density category being the strongest.

11 INTERMEDIATE POST SIZE DETERMINATION

11.1 Overview

After completing the second round of cantilever bogie tests, it was necessary to determine a post diameter in order to proceed with soil bogie tests. The method used to determine this size was a more refined version of the probability method presented previously. Similar to the former method, the new method established a required minimum force capacity of 9.5 kips, which was based on previous post testing. Also similar to the previous method, a 3 percent failure rate was established as an acceptable level of risk for the system to fail due to the failure of four consecutive posts when the system is subjected to the NCHRP Report 350 Test Level-3 criteria.

11.2 Probability Method for Determining Size

A post size had to be determined for each species that would allow each post to have a probability of fracture less than 40 percent. That is, a probability that the post will break, rather than rotate through the soil. Therefore, a strength distribution was needed for each species in order to determine the 40^{th} percentile MOR.

11.2.1 Strength Distribution Model

To develop such a model, a random sample was needed. In the study, the only truly random population sample was tested statically. All the dynamic tests were conducted on posts in subcategories of the population, and the percentage of the population that each category represented was unknown. Therefore, the only data that could be used to construct a population distribution was the random static testing.

The problem with using the static data to construct a distribution was that the strength values that needed to be considered were dynamic strength values, not static strength values. The dynamic strength exceeded the static strength. To account for this, a dynamic magnification factor was estimated and applied to the random static test results. The dynamic magnification factor was determined based on the testing in the individual subcategories of Baseline, High Ring Density, and Knots. The static and dynamic tests were compared and the ratio between them was determined for each category within each species, as shown in Table 36 and Table 37. This adjustment was made for both the first and second round cantilever tests, and the overall average for each species was used as the final magnification factor.

Looking carefully at the data, one will notice that there are some apparent shortcomings in this determination. Clearly, there is a large variability in the dynamic magnification factor and the average MOR values. In some cases such as the round 1 Ponderosa Pine tests, the MOR trend between categories is different for the static and dynamic tests. Another weakness is the arrangement of knots. In the second round, the dynamic tests were completed with the most knotty face as the impact face. This was not the case for the static tests, and likely resulted in a misleadingly low dynamic magnification factor. If this is the case, the shortcoming will result in a low dynamic MOR and hence a high suggested diameter.

The magnification factor was then applied to the static MOR, generating a random sample of dynamic test results that could be used to determine the size of post necessary to resist the soil forces.

Table 36. Dynamic Magnification Factor - Round 1 Bogie Testing

Round 1 Tests			Knots	Baseline	HRD	Average
Ponderosa Pine	Average MOR (ksi)	Static Testing	3.9	4.7	6.65	
		Dynamic Testing	6.5	5.66	9.18	
	Dynamic Magnification Factor		1.67	1.20	1.38	1.42
Douglas Fir	Average MOR (ksi)	Static Testing	6.16	7.04	7.29	
		Dynamic Testing	8.83	7.5	9.5	
	Dynamic Magnification Factor		1.43	1.07	1.30	1.27

Table 37. Dynamic Magnification Factor - Round 2 Bogie Testing

Round 2 Tests			Knots	Baseline	HRD	Average	Overall Average
Ponderosa Pine	Average MOR (ksi)	Static Testing	5.069	5.069	6.607		
		Dynamic Testing	6.65	7.32	7.55		
	Dynamic Magnification Factor		1.31	1.44	1.14	1.30	1.36
Douglas Fir	Average MOR (ksi)	Static Testing	5.775	6.047	9.112		
		Dynamic Testing	7.22	7.61	10.04		
	Dynamic Magnification Factor		1.25	1.26	1.10	1.20	1.24

Values presented in Table 36 include the inertial effects found in the first round of testing which may overestimate the dynamic magnification factors. To account for this, the inertial spikes were removed from the data and the dynamic magnification factors were re-calculated and are presented in Table 38.

Table 38. Dynamic Magnification Factor Excluding Inertial Effects

Round 1 Tests			Knots	Baseline	HRD	Average	Overall Average
Ponderosa Pine	Average MOR (ksi)	Static Testing	3.9	4.7	6.65		
		Dynamic Testing	5.6	5.4	8.8		
	Dynamic Magnification Factor		1.44	1.15	1.32	1.30	1.30
Douglas Fir	Average MOR (ksi)	Static Testing	6.16	7.04	7.29		
		Dynamic Testing	8.4	6.3	9.5		
	Dynamic Magnification Factor		1.36	0.89	1.30	1.19	1.20

With the unknown effects of the inertia spike on the fracture of the post discussed in Chapter 7, the lower dynamic magnification factors may predict dynamic strengths that are below the actual capacity of the posts. However, including the inertial effects may over-estimate actual dynamic strengths. In addition, the dynamic magnification factors calculated from the second round of testing may also underestimate actual dynamic strengths as discussed previously.

Therefore, both sets of dynamic magnification factors were used in the subsequent calculations. Since the two effects likely offset one another, the results based on the original magnification factors, including inertial effects, are presented within the text. The results based on the modified magnification factors, excluding inertial effects, are presented in Appendix F. The final size recommendation, excluding inertial effects, increased the target diameter for Ponderosa Pine by 6.35 mm (0.25 in.), but did not change the Douglas Fir results.

With this dynamic adjustment completed, there was still one stipulation that was unaccounted for, the grading criteria. Clearly, if all grades of posts were eligible to be used in the system, the average MOR would be lowered significantly. This in turn would increase the required post diameter. Therefore, it was decided that a grading criteria should be established to specify the minimum post quality that was acceptable for use in the system. The grading criteria needed to be strict enough to assure a high quality, and therefore a relatively small post size, but loose enough to include a large percentage of the population that it remained economical to produce the posts.

The final grading criteria were determined by investigating the effects on the average MOR of removing a portion of the posts within each species that failed to meet a certain grading criteria. For instance, within the Ponderosa Pine species, removing the posts with knots exceeding 102 mm (4 in.) in diameter and ring densities less than or equal to 6 rings-per-inch, raised the average MOR by 2 percent, increased its standard deviation by 6 percent, and only eliminated 8 percent of the population. For Douglas Fir, the criteria raised the MOR by 3 percent, decreased the standard deviation by 8 percent, and eliminated 17 percent of the population. The final criteria are presented below.

Douglas Fir:

- Maximum 2 in. diameter knot size.
- Ring of 6 rings-per-inch or more.

Ponderosa Pine:

- Maximum 4 in. diameter knot size.
- Ring density of 6 rings-per-inch or more.

After the grading criteria were specified, the random samples were sorted to exclude those posts that would not have fallen into the acceptable range. The remaining acceptable samples made up the target population and were used to develop a strength distribution that was in turn used to determine the acceptable diameters. Distribution plots for both the random population sample and the target population sample are shown in Figure 45 and Figure 46 for a generated sample of 1000 posts each. Static MOR, dynamic MOR, and the respective standard deviations are shown in Table 39 and Table 40 for the random and target populations of each species.

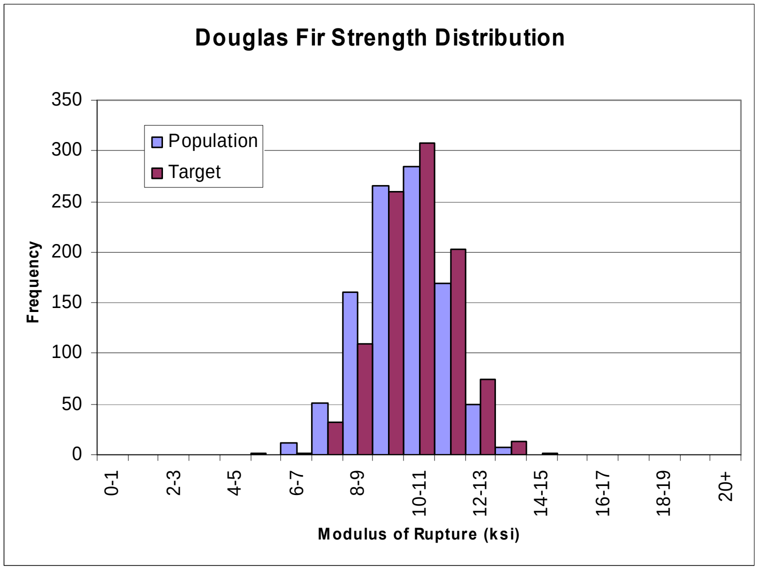


Figure 45. Douglas Fir Population and Target Population Strength Distribution

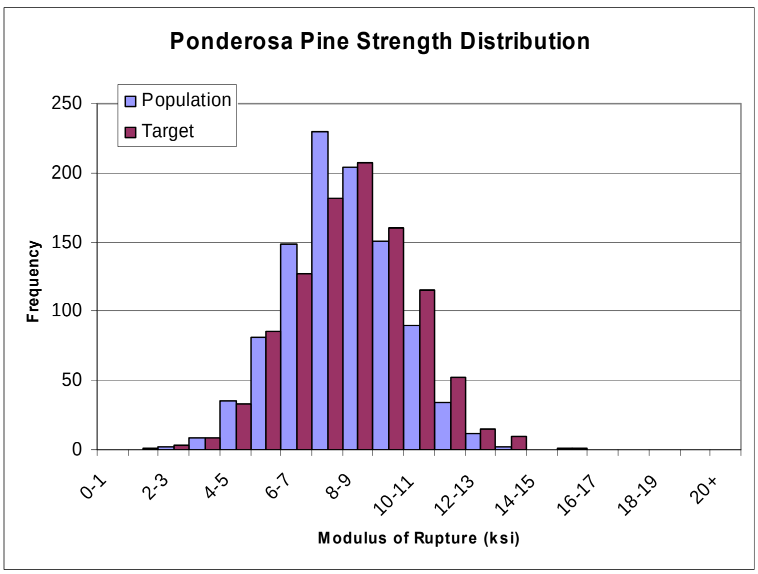


Figure 46. Ponderosa Pine Population and Target Population Strength Distribution

It is clear from the two figures and tables that the target population has a higher mean MOR than the general population. This is reasonable since the target population excludes some posts which fall at the lower end of the population distribution in terms of quality. From Table 39 and Table 40, it is apparent that the target category for Ponderosa

Pine was less of an improvement than that for Douglas Fir. With the MOR jumping by only 0.9 MPa (0.13 ksi), and the standard deviation increasing, the minimum diameter calculated for the population and the target population may be very similar as will be discussed in Section 11.2.2. However, it is important to maintain some minimum grading criteria so that timber producers will not allow poorer and poorer material into the manufacturing process.

Table 39. Douglas Fir Random Sample Testing Results

Douglas Fir				
	Static Testing Results		Adjusted Dynamic Results	
Sample	Mean MOR (ksi)	Standard Deviation (ksi)	Mean MOR (ksi)	Standard Deviation (ksi)
Random Population Sample	8.10	1.07	10.00	1.33
Target Population Sample			10.34	1.22

Table 40. Ponderosa Pine Random Sample Testing Results

Ponderosa Pine				
	Static Testing Results		Adjusted Dynamic Results	
Sample	Mean MOR (ksi)	Standard Deviation (ksi)	Mean MOR (ksi)	Standard Deviation (ksi)
Random Population Sample	5.95	1.33	8.09	1.81
Target Population Sample			8.22	1.93

11.2.2 Minimum Size Determination

The proper minimum size was then determined using elastic bending equations and the estimated MOR. As stated previously, 60 percent of the posts must withstand an impact force of 42 kN (9.5 kips) at a height of 632 mm (24.875 in.), or a bending moment capacity of 26.7 kN-m (236 kip-in.). This meant that the post diameter needed to be selected so a post with an ultimate strength equal to the 40 percent MOR value would have a moment capacity of 26.7 kN-m (236 kip-in.). The equation used to determine the diameter was a form of the simple elastic bending stress equation and is shown below.

$$d = \sqrt[3]{\frac{(32)(\mathrm{L})(P)}{(\pi)(40\%\ \mathrm{MOR})}}$$

Mean MOR, standard deviation, 40 percent MOR, and the calculated minimum diameter are shown in Table 41 for both Douglas Fir and Ponderosa Pine graded populations. Final minimum diameter values were rounded up from the values shown to the nearest quarter of an inch for manufacturing purposes.

Table 41. Minimum Diameter Calculation

	Douglas Fir		Ponderosa Pine	
	Mpa	**(ksi)**	**Mpa**	**(ksi)**
Mean MOR	71.29	(10.34)	56.67	(8.22)
Standard Deviation	8.41	(1.22)	13.31	(1.93)
40% MOR	69.15	(10.03)	53.30	(7.73)
Minimum Diameter	158 mm	(6.21 in.)	172 mm	(6.78 in.)

As alluded to, the minimum calculated diameter for the Ponderosa Pine population was 173 mm (6.8 in.), only 0.5 mm (0.02 in.) larger than the target population. Although this is the case, the minimum grading criteria needs to remain for quality assurance purposes as discussed in Section 11.2.1.

The minimum diameter was determined, and an acceptable range and target diameter needed to be established. The range of acceptable post diameters was set at 1 in. to allow some tolerance in the manufacturing process. The lower bound of the range was set at the minimum diameter and the target diameter was set 6.4 mm (0.25 in.) above the lower bound. The calculated diameters are shown below. The minimum diameter for each species was 12.7 mm (0.5 in.) less than the diameter recommended previously.

Douglas Fir:

- $165\ \mathrm{mm}\,^{+19\ \mathrm{mm}}_{-6\ \mathrm{mm}}\quad \left(6.5\ \mathrm{in.}\,^{+0.75\ \mathrm{in.}}_{-0.25\ \mathrm{in.}}\right)$

Ponderosa Pine:

- $184\text{ mm}\begin{matrix}+19\text{ mm}\\-6\text{ mm}\end{matrix}\quad\left(7.25\text{ in.}\begin{matrix}+0.75\text{ in.}\\-0.25\text{ in.}\end{matrix}\right)$

Target values were specified simply to give producers a size that was above the minimum requirement. The actual target diameter could have been selected as any value within the range and was much less important than the range itself. Although post producers will attempt to find posts meeting the target diameter, when few are available, they will inevitably select posts from their stockpile that fall anywhere within the specified range.

Rounding the minimum diameter up to the nearest ¼ in. resulted in a probability of failure for each post that was lower than originally suggested. For 159-mm (6.25-in.) Douglas Fir posts, the probability of failure was just over 35 percent, 5 percent lower than desired. For Ponderosa Pine, the increase to 178 mm (7 in.) lowered the probability of failure to 27 percent, 13 percent lower than what was needed. These adjustments also increase the reliability of the guardrail system. For a Douglas Fir system, the probability of failure, due to four consecutive failed posts, with 159-mm (6.25-in.) diameter posts was about 1.5 percent. For a 178-mm (7-in.) Ponderosa Pine system, the probability of failure was less than 1 percent.

Finally, allowing posts with diameters larger than the target values significantly reduces the probability of failure for each post and the system. For instance, the probability that a 178-mm (7-in.) diameter Douglas Fir post will fail is 0.4 percent, leading to a very small probability that the system will fail due to the failure of the posts. The same is true for Ponderosa Pine in which a 197-mm (7.75-in.) diameter post has a probability of failure just under 6 percent. This also corresponds to a very small system failure probability.

12 PHYSICAL TESTING – SOIL BOGIE TESTING

12.1 Scope

After determining the minimum diameter required for the posts to rotate in soil rather than fracture, soil bogie tests were completed to verify the results. Initially, a total of six soil tests were completed for Douglas Fir and Ponderosa Pine, three for each species. A 1016-mm (40-in.) embedment depth, the standard embedment depth for the MGS system, was used as the starting point for the first two tests of each species. The tests were conducted at approximately 25 mph. This velocity was chosen so the kinetic energy of the bogie exceeded the energy absorbed in the previous soil-post tests which were used to determine the approximate peak load. Prior to testing, the moisture content and diameter of each post was measured and recorded. The soil bogie test setup is shown in Figure 47.

For the preliminary soil tests, the species of the posts was ignored, assuming that the behavior of a 203 mm (8 in.) diameter Ponderosa Pine post and a 203 mm (8 in.) Southern Yellow Pine post will be the same as long as neither post fractures. Therefore, the species of the post did not always correspond to the test name. Based on the same reasoning, the posts were not soaked in water as soaking should not have affected the soil response.

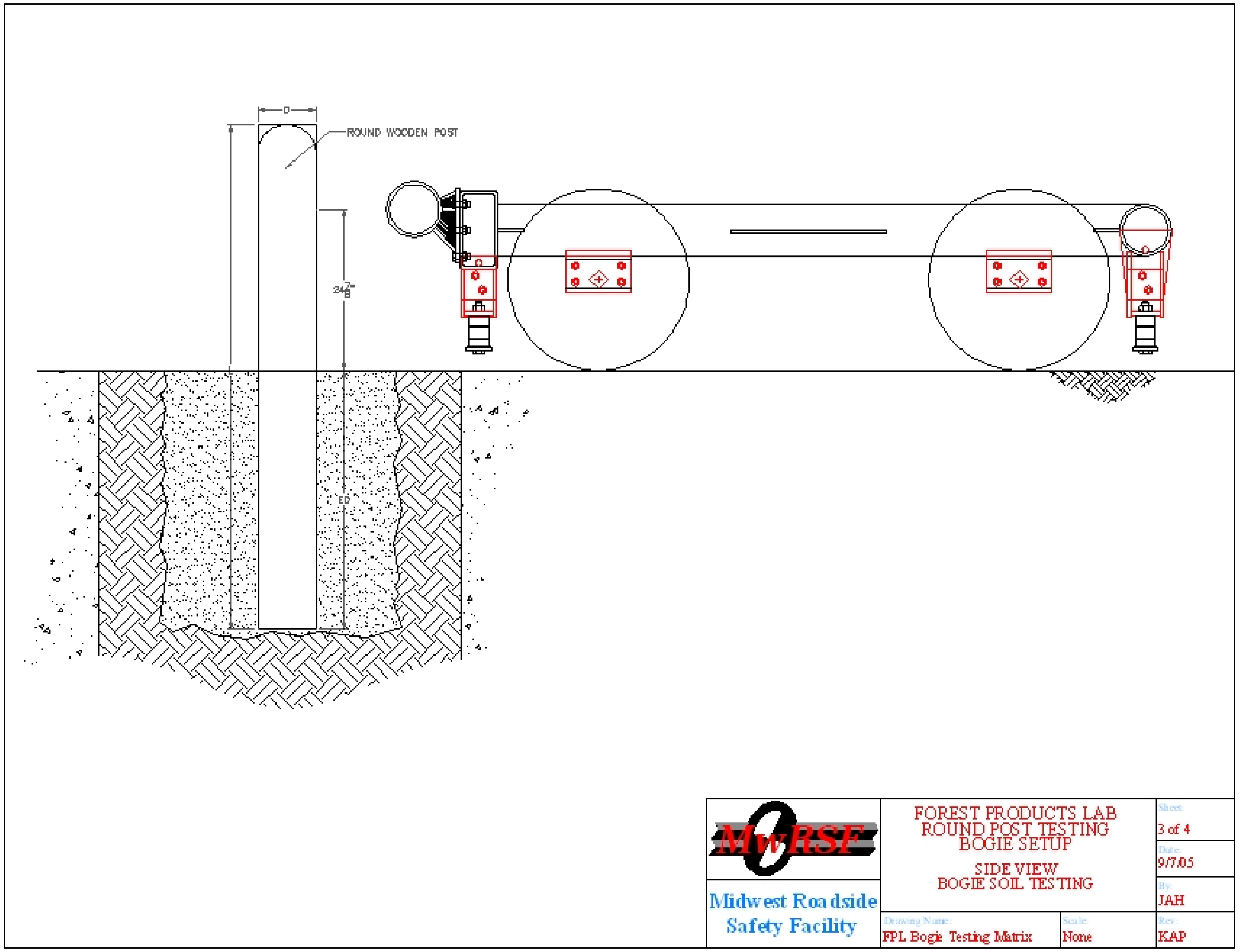


Figure 47. Soil Bogie Test Setup

12.2 Results

The raw data was once again recorded using a triaxial piezoresistive accelerometer system recording at 3,200 Hz, three pressure tape switches, and a series of cameras including two high speed VITcam digital video cameras, and a JVC digital video camera.

The data was processed using the same methods as the cantilever sleeve tests. The end of the test was determined as the most appropriate of the first, second, or third time the acceleration trace crossed the X-axis from positive to negative. Summaries of the results for all the soil tests are presented in Table 42 and Table 43, with complete results for each test presented in Appendix G.

The energy and deflection quantities were estimated at three times throughout the tests, the time corresponding to the peak force, the time corresponding to 381 mm (15 in.) of deflection, and at the end of the test. Data was provided at 381 mm (15 in.) deflection because previous studies show that the rail typically separates from the post at around 381 mm (15 in.) of deflection, making the post ineffective beyond this point.

12.2.1 Ponderosa Pine

As shown in Table 42, the first two Ponderosa Pine tests, PP-31 and 32, ended in post fracture and absorbed a very small amount of energy compared with previous soil tests. When this occurred, the embedment depth for the third test, PP-33, was reduced to 940 mm (37 in.), but the post still fractured.

Table 42. Soil Bogie Test Overview

	Post Test No.	Test Date	Species	In Soil Diameter mm	(in.)	Embedment Depth (in.)	Moisture Content (%)	Impact Velocity m/s	(mph)	Final Post Status
Ponderosa Pine	PP-31	9/16/2005	PP	183.76	(7.24)	40.00	29	11.7	(26.2)	Fractured
	PP-32	9/19/2005	PP	184.77	(7.28)	40.00	48	10.9	(24.5)	Fractured
	PP-33	9/29/2005	SYP	185.93	(7.32)	37.00	10	11.5	(25.7)	Fractured
			Avg.	**184.82**	**(7.28)**		**29**	**11.4**	**(25.5)**	
			St. Dev.	**1.09**	**(0.04)**		**19**	**0.4**	**(0.9)**	
	PP-34	11/7/2005	PP	202.44	(7.97)	37.00	25	10.9	(24.3)	Rotated
	PP-35	11/7/2005	PP	200.66	(7.90)	37.00	24	11.3	(25.3)	Rotated
	PP-36	11/7/2005	PP	199.14	(7.84)	37.00	20	10.6	(23.8)	Rotated
	PP-37	11/7/2005	PP	194.06	(7.64)	37.00	23	11.2	(25.1)	Rotated
			Avg.	**199.07**	**(7.84)**		**23**	**11.0**	**(24.6)**	
			St. Dev.	**3.61**	**(0.14)**		**2**	**0.3**	**(0.7)**	
Douglas Fir	DF-31	9/19/2005	SYP	165.48	(6.52)	40.00	17	11.1	(24.8)	Rotated
	DF-32	9/19/2005	PP	165.48	(6.52)	40.00	15	10.9	(24.4)	Fractured
	DF-33	9/23/2005	SYP	168.28	(6.63)	37.00	17	10.8	(24.2)	Fractured
			Avg.	**166.41**	**(6.56)**		**16**	**10.9**	**(24.4)**	
			St. Dev.	**1.61**	**(0.06)**		**1**	**0.1**	**(0.3)**	
	DF-34	10/4/2005	DF	181.86	(7.16)	37.00	15	11.2	(25.1)	Rotated
	DF-35	10/5/2005	DF	180.34	(7.10)	37.00	19	11.5	(25.7)	Rotated
	DF-36	10/5/2005	DF	175.26	(6.90)	37.00	18	11.1	(24.8)	Fractured
			Avg.	**179.15**	**(7.05)**		**17**	**11.3**	**(25.2)**	
			St. Dev.	**3.46**	**(0.14)**		**2**	**0.2**	**(0.4)**	

Table 43. Soil Bogie Test Results Summary

	Post Test	Peak Force							381 mm (15 in.) Deflection			Final				
		Time	Force		Deflection		Energy		Time	Energy		Time	Deflection		Energy	
	No.	ms	kN	(kips)	mm	(in.)	kJ	(kip-in.)	ms	kJ	(kip-in.)	ms	mm	(in.)	kJ	(kip-in.)
Ponderosa Pine	PP-31	11.9	50.5	(11.3)	137	(5.4)	4.22	(37.4)	34.7	9.63	(85.3)	57.2	618	(24.3)	10.17	(90.0)
	PP-32	6.3	43.6	(9.8)	68	(2.7)	1.20	(10.6)	N/A	N/A		29.4	312	(12.3)	3.34	(29.6)
	PP-33	5.6	52.2	(11.7)	64	(2.5)	1.44	(12.8)	35.3	11.20	(99.2)	102.8	969	(38.1)	24.34	(215.4)
	Avg.	**7.9**	**48.7**	**(11.0)**	**90**	**(3.5)**	**2.29**	**(20.3)**	**35.0**	**10.42**	**(92.2)**	**63.1**	**633**	**(24.9)**	**12.62**	**(111.7)**
	St. Dev.	**3.5**	**4.6**	**(1.0)**	**41**	**(1.6)**	**1.68**	**(14.9)**	**0.4**	**1.11**	**(9.8)**	**37.1**	**329**	**(12.9)**	**10.71**	**(94.8)**
	PP-34	5.6	93.6	(21.0)	61	(2.4)	2.60	(23.0)	38.8	14.39	(127.3)	136.6	1059	(41.7)	29.37	(259.9)
	PP-35	5.3	76.0	(17.1)	60	(2.3)	2.00	(17.7)	35.9	9.65	(85.4)	147.8	1322	(52.0)	26.41	(233.8)
	PP-36	5.3	88.4	(19.9)	56	(2.2)	2.28	(20.2)	38.1	7.52	(66.6)	130.0	1179	(46.4)	17.88	(158.2)
	PP-37	5.3	62.2	(14.0)	59	(2.3)	1.74	(15.4)	35.6	6.69	(59.2)	149.1	1401	(55.2)	21.44	(189.7)
	Avg.	**5.4**	**80.0**	**(18.0)**	**59**	**(2.3)**	**2.16**	**(19.1)**	**37.1**	**9.56**	**(84.6)**	**140.9**	**1240**	**(48.8)**	**23.77**	**(210.4)**
	St. Dev.	**0.1**	**14.0**	**(3.1)**	**2**	**(0.1)**	**0.37**	**(3.3)**	**1.6**	**3.45**	**(30.5)**	**9.2**	**152**	**(6.0)**	**5.12**	**(45.3)**
Douglas Fir	DF-31	5.9	40.9	(9.2)	65	(2.6)	1.21	(10.7)	36.6	10.62	(94.0)	177.5	1346	(53.0)	33.25	(294.3)
	DF-32	5.9	57.1	(12.8)	64	(2.5)	1.62	(14.3)	N/A	N/A		35.6	376	(14.8)	3.60	(31.9)
	DF-33	6.3	57.1	(12.8)	67	(2.6)	1.64	(14.5)	36.9	6.53	(57.8)	60.0	608	(23.9)	7.75	(68.6)
	Avg.	**6.0**	**51.7**	**(11.6)**	**66**	**(2.6)**	**1.49**	**(13.2)**	**36.8**	**8.58**	**(75.9)**	**91.0**	**777**	**(30.6)**	**14.87**	**(131.6)**
	St. Dev.	**0.2**	**9.3**	**(2.1)**	**1**	**(0.1)**	**0.24**	**(2.1)**	**0.2**	**2.89**	**(25.6)**	**75.9**	**506**	**(19.9)**	**16.05**	**(142.1)**
	DF-34	6.3	81.9	(18.4)	70	(2.7)	2.49	(22.0)	36.3	9.43	(83.5)	151.9	1344	(52.9)	25.56	(226.3)
	DF-35	5.6	52.8	(11.9)	64	(2.5)	1.59	(14.1)	35.9	14.25	(126.1)	144.7	1202	(47.3)	32.14	(284.5)
	DF-36	5.3	50.1	(11.3)	59	(2.3)	1.34	(11.8)	36.9	12.64	(111.9)	69.1	682	(26.8)	14.01	(124.0)
	Avg.	**5.7**	**61.6**	**(13.9)**	**64**	**(2.5)**	**1.80**	**(16.0)**	**36.4**	**12.11**	**(107.2)**	**121.9**	**1076**	**(42.4)**	**23.90**	**(211.6)**
	St. Dev.	**0.5**	**17.6**	**(4.0)**	**5**	**(0.2)**	**0.61**	**(5.4)**	**0.5**	**2.45**	**(21.7)**	**45.9**	**349**	**(13.7)**	**9.18**	**(81.2)**

Analyzing the data showed that the peak force averaged 48.7 kN (11.0 kips), with the highest peak reaching 52.2 kN (11.7 kips). This average peak force would produce a maximum stress of 53 MPa (7.7 ksi), which was still less than the average MOR for the species. However, 41 percent of the post population was weaker than this, which implied that all three posts were in the lower 41 percent of the distribution.

The 48.7 kN (11.0 kips) average was 15 percent higher than the anticipated 42 kN (9.5 kips), suggesting that the posts were undersized. This high force peak may have been due to the differences in the cross-sections of the round wooden posts and the NPGB tests used to estimate the force. Although their round cross-section should more easily cut through the soil, the wooden posts were wider than the steel posts, counter acting the effects of the shape. The wooden posts also were likely to have different surface interactions with the soil due to the roughness of the wood grain that was not present in the steel posts. Finally, differences in the soil gradation, amount of soil compaction, and methods used to compact the soil could have had some effect.

12.2.2 Douglas Fir

Unlike the Ponderosa Pine tests, one of the first two Douglas Fir tests ended in soil failure, with the rotation of the post absorbing 33.25 kJ (294.3 kip-in.) of energy as shown in Table 43. Since one of the posts did fail, a reduced embedment depth of 940 mm (37 in.) was also tried for the Douglas Fir posts, and as in Ponderosa Pine, this shallower post fractured rather than rotating.

With a 51.7 kN (11.6 kips) average peak load for the first three tests, the data analysis again suggested that the peak forces in the soil tests were higher than anticipated. Unlike Ponderosa Pine, the average peak force for Douglas Fir corresponded to a maximum bending stress that exceeded the average MOR, suggesting that over half of the post population should have failed.

The average peak force exceeded the predicted load by 22 percent, and the highest of the peaks reached 57.1 kN (12.8 kips), exceeding the prediction by nearly 35 percent. The results suggested the Douglas Fir posts were also too small. Again the increased force was likely due to differences in cross-section, surface friction, and soil compaction between the NPGB and round wooden post tests.

In order for the posts to rotate through the soil, one of two changes needed to be made. The first option was to decrease the force required for the post to move through the soil. The second option was to increase the force required to break the post. A decreased in the soil force could be reached by reducing the embedment depth of the posts from 940 mm (37 in.) to 864 mm (34 in.) or less, but doing so might have caused the posts to be pulled out of the soil before they were allowed to rotate through the soil. This behavior was observed by Kuipers and Reid in their NPGB post study, in which the W6x16 steel posts began pulling out of the soil at an embedment depth of 940 mm (37 in.). The study showed that the posts which had pulled out of the soil absorbed less energy than those did not. The pullout phenomenon was not observed in the round wood post testing, but reducing the embedment depth further, may well have led to the same problem.

To increase the post breaking force, the grading criteria could be tightened, allowing only top quality posts to be installed in the system, or the diameter of the posts could be increased. Tightening the grading criteria would eliminate a larger percentage of the posts, making the system more and more expensive to construct. Increasing the diameter would increase the soil resistance and also the post rotation force which already exceeded the optimal force level of 42.3 kN (9.5 kips) for MGS.

Although a reduced post embedment depth could have been tested, the results of such testing would not have been conclusive. In the strong soil used for the testing, post pull-out may not have occurred even at the reduced embedment depth. In the weaker soils that are found in the majority of the guardrail installation locations, the posts may pull-out of the soil with a much lower resistance. Therefore, testing at a reduced embedment depth might not have accurately predicted the potential for post pull-out.

Of the two remaining options, adjusting the grading criteria was avoided to keep the cost of the system as low as possible and allow the highest percentage of forest thinning material to be used. The final option, increasing the post diameter, was selected although the impact force exceeded the optimum level. Choosing this option, the system would still function adequately, just not optimally.

12.3 Re-Evaluation of Post Size

After the initial soil bogie tests showed that the selected diameter for the two species was too small, the size was re-evaluated. Once again the refined probability method was employed. The anticipated peak force was increased to 53 kN (12 kips) for the Douglas Fir samples, and 58 kN (13 kips) for the Ponderosa Pine samples. The anticipated force level was higher for the Ponderosa Pine species to account for the larger diameter which would be required to move more soil and would create a flatter cross-section that was more resistant to soil rotation. In addition, a more realistic soil pressure distribution was used to determine the maximum moment in the post. The assumed soil distribution was based on a study conducted by Goeller at MwRSF [22]. Goeller found that the soil distribution shown in Figure 48 was the most accurate. However, it did not exactly match the results of the round post testing.

In the Douglas Fir and Ponderosa Pine testing, the fracture surface ranged from 51 mm (2 in.) to 203 mm (8 in.) lower than those found in the cantilever tests, and averaged about 102 mm (4 in.) below the ground. Assuming this would also be the location of the maximum moment, the soil pressure distribution needed to be adjusted to reflect this. The second check that was made was to determine the rotation point of a round post during a soil test. Similar to Goeller's results, the rotation point was approximately 305 mm (12 in.) below the ground. Therefore, the soil pressure switched directions at 305 mm (12 in.) below the ground as before. Adjusting the pressure distribution so the maximum moment was approximately 102 mm (4 in.) below the surface resulted in the distribution shown in Figure 49.

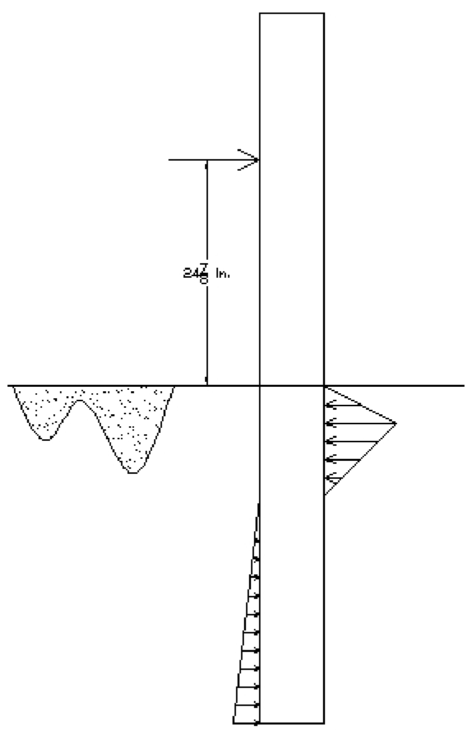


Figure 48. Initial Soil Pressure Distribution [22]

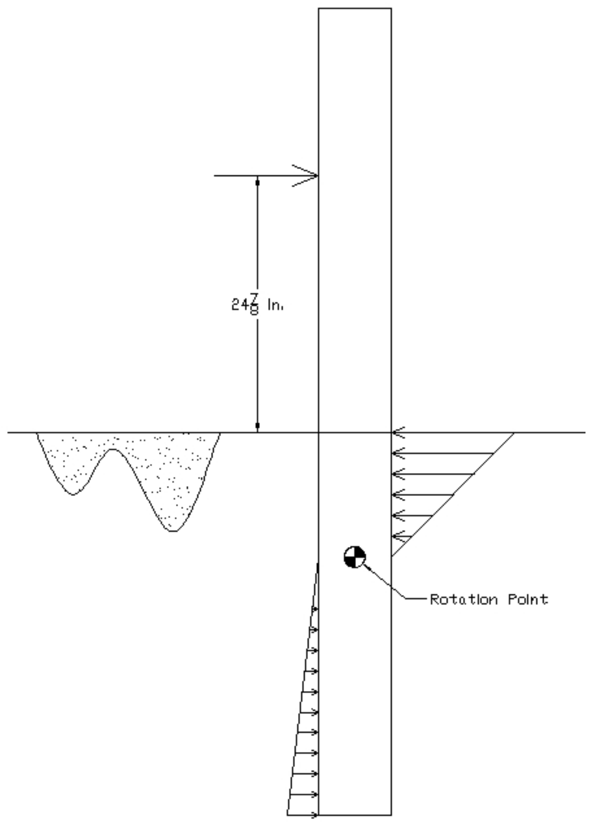


Figure 49. Soil Force Distribution

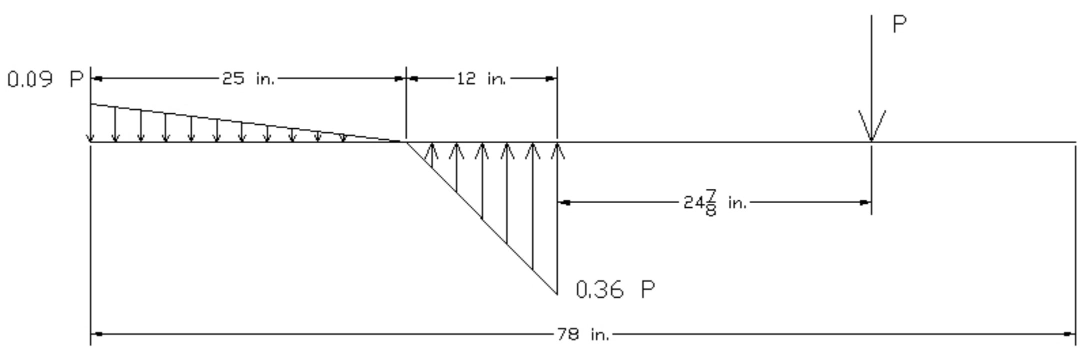


Figure 50. Post Free-Body Diagram

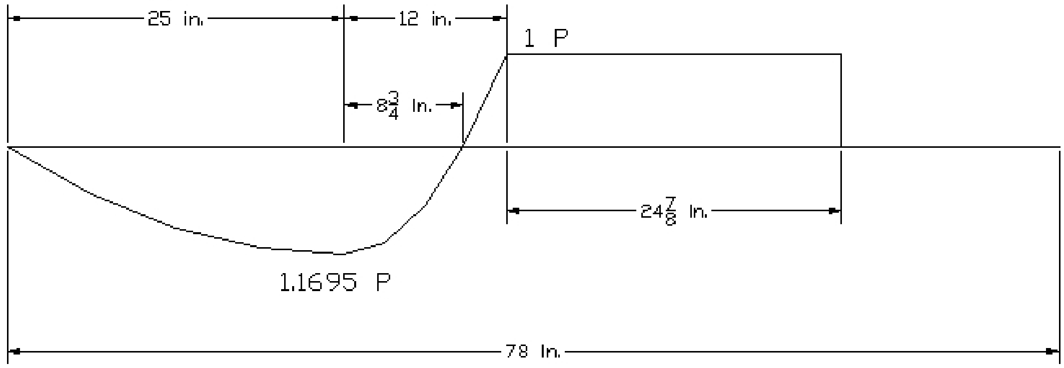


Figure 51. Post Shear Force Diagram

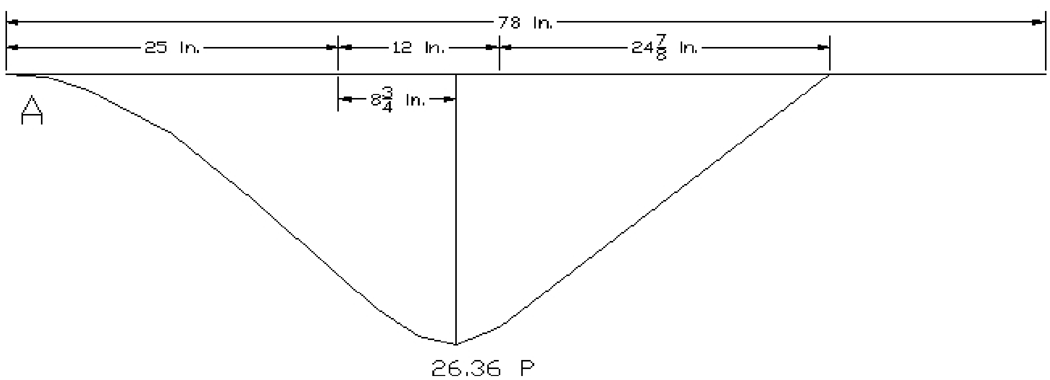


Figure 52. Post Bending Moment Diagram

The modified pressure distribution effectively increased the maximum moment by 6 percent from (24.875)(P) kip-in. to (26.387)(P) kip-in. as shown in Figure 52, where P was the peak load in kips at the impact height. It should be noted that the actual soil pressure distribution and rotation point vary with each individual test and depend on numerous factors such as soil compaction, soil moisture content, and embedment depth. Many soil pressure distribution models have been developed, but the distribution shown in Figure 49 seemed to fit the post fracture results the most closely.

With the increased peak force and modified pressure distribution, the probability method returned minimum diameter values of 195 mm (7.67 in.) for Ponderosa Pine and 174 mm (6.85 in.) for Douglas Fir. Rounding to the next highest quarter inch, the acceptable ranges of post sizes were determined as follows.

Ponderosa Pine:

$$203\,\text{mm}\,{}^{+19\,\text{mm}}_{-6\,\text{mm}} \quad \left(8.00\,\text{in.}\,{}^{+0.75\,\text{in.}}_{-0.25\,\text{in.}}\right)$$

Douglas Fir:

$$184\,\text{mm}\,{}^{+19\,\text{mm}}_{-6\,\text{mm}} \quad \left(7.25\,\text{in.}\,{}^{+0.75\,\text{in.}}_{-0.25\,\text{in.}}\right)$$

12.4 Results – Additional Soil Tests

As shown in Table 42, additional tests were conducted on posts with diameters exceeding the new minimum calculated diameter. An embedment depth of 940 mm (37 in.) was chosen for the tests, and the impact speed of 25 mph remained the same. Since the majority of the posts fractured in the previous tests, the decision was made to use the species of wood corresponding to the test name, unlike the initial soil tests.

12.4.1 Ponderosa Pine

Four additional soil tests were conducted for the Ponderosa Pine species. Post specifications are shown in Table 42, and results are shown in Table 43. Clearly for this series of tests, the energy absorbed through 381 mm (15 in.) of displacement increased with increasing diameter. The smallest post, 194 mm (7.64 in.) diameter, fell outside the acceptable range, but still ended in soil failure.

The absorbed energy after 381 mm (15 in.) of deflection was as small as 6.69 kJ (59.2 kip-in.) and as high as 14.39 kJ (127.3 kip-in.), higher than any of the other soil tests. The average energy was 9.56 kJ (84.6 kip-in.), which was lower than the 13.9 kJ (122 kip-in.) absorbed by a standard 152 mm x 203 mm (6 in. x 8 in.) rectangular wood post embedded at 940 mm (37 in.), tested at MwRSF in September, 2005. The average was also lower than the 10.5 kJ (92.5 kip-in.) of energy absorbed by standard W152x13.4 (W6x9) steel posts embedded at 940 mm (37 in.) [27]. This suggests that an MGS system utilizing round Ponderosa Pine posts would deflect more than a system constructed with steel posts or rectangular wood posts.

Clearly, there were significant differences in energy absorption between the Douglas Fir and Ponderosa Pine samples, with the average energy absorbed by the Ponderosa Pine posts less than 80 percent of that by Douglas Fir posts. There was also a large amount of variation between tests within the Ponderosa Pine species. At 381 mm (15 in.) of deflection, test no. PP-34 had absorbed more than twice as much energy as PP-37.

The differences in the testing were not consistent, nor entirely explainable by theory. Larger diameter posts should generate larger soil forces, but this was not always the case. Therefore, the differences must be attributed to other testing variables such as soil variation. The soil gradation, soil moisture content, amount of soil compaction, and method of soil compaction could all have made significant differences in the post-soil interaction, and therefore effect the post-soil forces.

12.4.2 Douglas Fir

Three additional tests were conducted for Douglas Fir, with Table 43 showing the results. The diameters for the three posts were 182 mm (7.16 in.), 180 mm (7.10 in.), and 175 mm (6.9 in.). Both tests conducted on posts with diameters within the acceptable range ended successfully with soil failure. However, test DF-36 did not result in soil failure, but rather post fracture. Although 175 mm (6.9 in.) did exceed the minimum suggested diameter of 173 mm (6.8 in.), the failure should not be alarming. The probability that such a post would fail under a 50.1 kN (11.3 kip) peak load was 19 percent. It seems reasonable that this specific post could have fallen within the 19 percent that should fail.

The energy absorbed by the post rotation at 381 mm (15 in.) ranged from 9.43 kJ (83.5 kip-in.) to 14.25 kJ (126.1 kip-in.), and averaged 12.11 kJ (107.2 kip-in.). In comparison, these values were lower than the energy absorbed by standard 152 mm x 203 mm (6 in. x 8 in.) rectangular wood posts in tests conducted at MwRSF in September, 2005, but higher than the standard W152x13.4 (W6x9) steel posts used in the MGS system [27]. Similar to Ponderosa Pine, this suggests that the deflection of a system using round Douglas Fir posts would be less than a system utilizing steel posts, but more than a system utilizing rectangular wood posts.

12.4.3 Testing Conclusion

Unlike the first set of soil tests, in the second round, less than 40 percent of the posts within each species failed. Even though the number of tests conducted was small, the results supported the conclusion that the suggested minimum diameter was no longer inadequate.

While this is true, one should notice that in several of the tests, the peak soil forces exceeded the target failure capacity. For instance, in test no. PP-34, the peak load of 93.6 kN (21.0 kips) exceeded the predicted 57.8-kN (13.0-kip) load by over 60 percent. For Douglas Fir, peak forces for test no. DF-34 exceeded the predicted 53.4-kN (12.0-kip) load by more than 50 percent.

This known, one might wonder why such a small percentage of the posts actually fractured. There are several possible explanations, the first of which is inertial effects. As discussed in Chapter 7, some of the force felt by the bogie vehicle was required to initiate movement in the post, not causing the post to bend. The inertial effects must have also existed in soil testing, and may have been even greater than the cantilever tests since the bogie not only had to move the post, but also the soil. Therefore, peak forces felt by the bogie could have been much higher than those felt by the post, possibly over-estimating the required diameter.

A second explanation is the quality of the posts. With a small number of tests, the quality of sample could have been higher or lower than average. If the sample was higher than average, the posts could have easily carried the higher load without fracture. However, not knowing the strength of the sample, it is impossible to know if this was the case.

13 BARRIER VII MODELING - SYSTEM EVALUATION

As a final step prior to a full-scale crash test, Barrier VII [8] was utilized to predict the behavior of the MGS system constructed with the recommended round wooden post sizes.

13.1 Round Post Properties – BARRIER VII Model

Representative round post models needed to be developed to generate more accurate simulations with BARRIER VII. Since the results from the testing varied extensively and inconsistently, the seven tests were combined to determine a single BARRIER VII round post model. This action was reasonable because the target properties for the posts were independent of their species, and no adjustments will be made to the system to account for any differences.

In the BARRIER VII model, post load curves were approximated using a perfectly plastic model similar to that shown in Figure 53. To define the curve, the stiffness, yield force, yield moment, and maximum deflection were defined.

Although the model is not a perfect representation of the test results, it does offer a very simple and somewhat accurate representation of a post rotating through soil. In the initial portion of the curve, the force resistance increases as the post begins to move and compress the soil. Eventually, the force reaches its yield point, P_y, and the stress on the soil is great enough that the soil fails and allows the post to rotate through with a constant force. At some point, the post reaches a maximum deflection, Δ_{Fail}, at which it separates from the rail making it ineffective, with no resistive capacity.

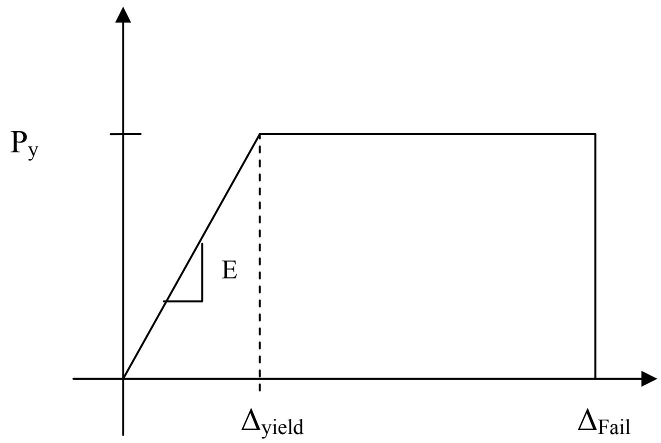
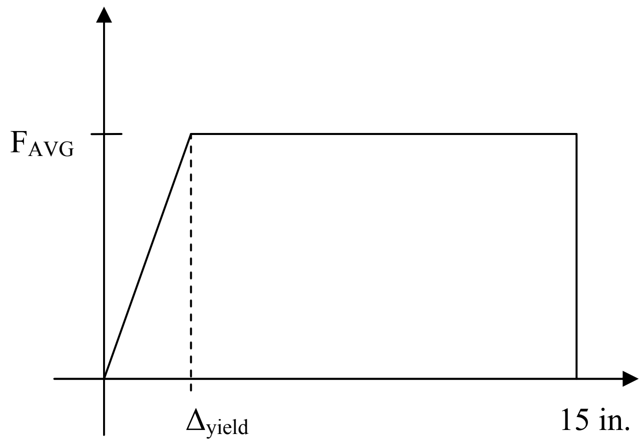


Figure 53. Barrier VII Post Strength Model

Knowing that in a typical impact, the posts and the rail separate after approximately 381 mm (15 in.) of deflection, the parameters of the post model were based on the behavior of the post up to that point. Therefore, the maximum deflection was set at 381 mm (15 in.).

To determine the yield moment, M_y, the average force, P_y, through the 381 mm (15 in.) deflection was multiplied by the impact height, h. The average force was determined by equating the average energy dissipated in the actual tests to that in the BARRIER VII force model, as shown in the calculations below. A similar procedure, in which the average slope of the actual initial force spike was equated to the slope of the BARRIER VII model, was used to determine the stiffness. Calculations are also shown below.



$$AREA = F_{AVG}\left(\left(\frac{\Delta y}{2}\right) + (15 - \Delta y)\right)$$

AREA = Average Energy at 15 in.

$$SLOPE = \frac{F_{AVG}}{\Delta y}$$

SLOPE = Average Slope

Properties from the seven soil tests that were relevant to the BARRIER VII post model are summarized in Table 44 for the lateral direction. The average energy and average slope were used to determine F_{AVG} equal to 28.9 kN (6.49 kips) and Δ_y equal to 24 mm (0.96 in.). A plot of the seven soil tests with the BARRIER VII lateral post model is shown in Figure 54.

Table 44. BARRIER VII Round Wooden Post Lateral Properties Summary

Test No.	Energy at 381 mm (15 in.)		Peak Force		Deflection		Slope	
	kJ	(kip-in.)	kN	(kips)	mm	(in.)	kN/mm	(kips/in.)
DF-34	9.4	(83.5)	81.9	(18.4)	70	(2.7)	1.17	(6.72)
DF-35	14.3	(126.1)	52.8	(11.9)	64	(2.5)	0.83	(4.69)
DF-36	12.6	(111.9)	50.1	(11.3)	59	(2.3)	0.85	(4.86)
PP-34	14.4	(127.3)	93.6	(21.0)	61	(2.4)	1.54	(8.82)
PP-35	9.6	(85.4)	76.0	(17.1)	60	(2.3)	1.27	(7.27)
PP-36	7.5	(66.6)	88.4	(19.9)	56	(2.2)	1.58	(8.99)
PP-37	6.7	(59.2)	62.2	(14.0)	59	(2.3)	1.05	(6.00)
Overall Average	10.7	(94.3)	72.1	(16.2)	61	(2.4)	1.18	(6.75)

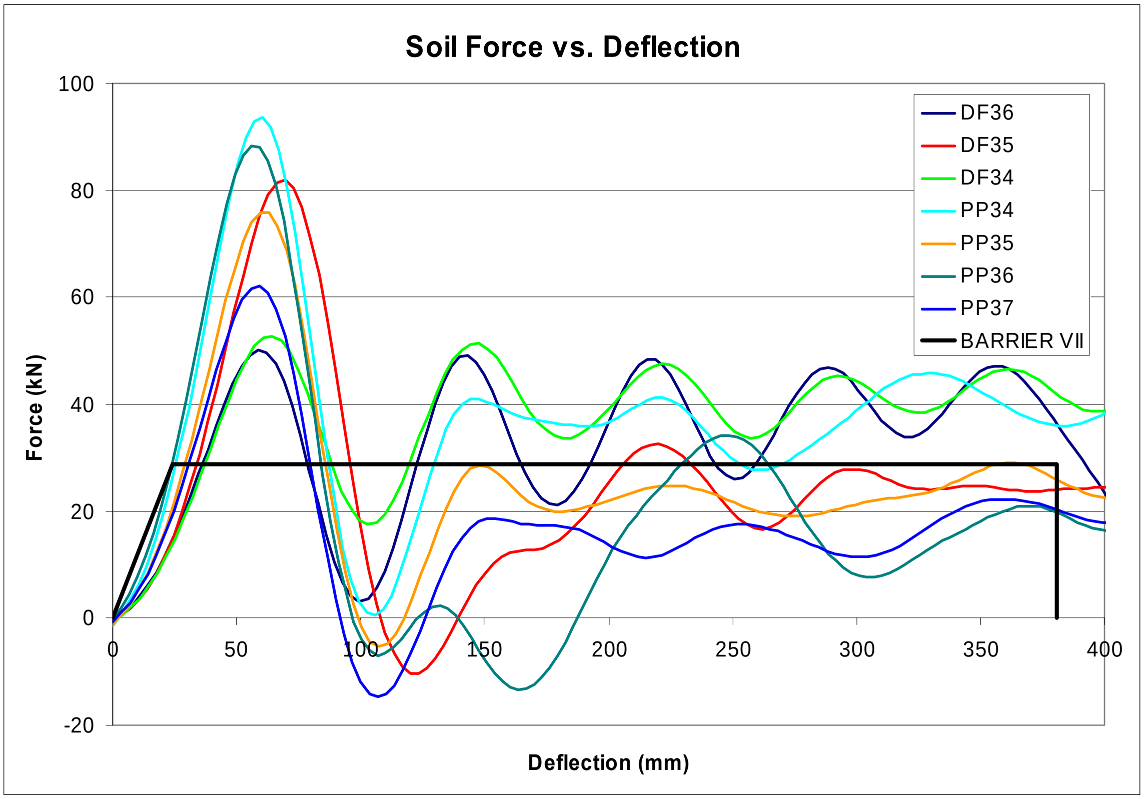


Figure 54. Lateral Capacity BARRIER VII Model

Since the longitudinal load on the posts is applied very slowly, the capacity in that direction was based on the results of static testing by Jeyapalan [15], previously discussed in Chapter 2. For this direction of loading, the BARRIER VII F_{AVG} and Δ_y properties were determined as 16.5 kN (3.7 kips) and 70 mm (2.76 in.), respectively. For comparison purposes, the BARRIER VII parameters used for the standard MGS model with W6x9 steel posts were F_{AVG} = 25.8 kN (5.8 kips) and Δ_y = 24 mm (0.96 in.).

13.2 BARRIER VII Results

BARRIER VII simulations were completed for a baseline model and models with 1, 2, 3, and 4 consecutive weak posts. The simulations were conducted in same manner as before with the same weak post model. Once again, the parameters collected from the simulations included maximum dynamic deflection, maximum rail tension, rail slope, and wheel snag. Results from the simulations are presented in Table 45.

Table 45. FPL BARRIER VII Results Summary

No. Weak	Maximum Deflection	Maximum Rail Tension	Pocketing Analysis		Snag Analysis **		
			3 Node	5 Node	Node	Snag	dy
	(in.)	(kips)	(Rail Slope)		(no.)	(in.)	(in.)
0	40.5	65.9	0.345	0.317	96	6.29	14.38
1	44.6	66.7	0.357	0.331	105	6.14	14.66
2	47.9	68.0	0.357	0.332	114	6.36	15.00
3	49.9	68.1	0.358	0.338	122	6.16	14.99
4	52.2	69.2	0.357	0.337	130	6.36	14.99

** Wheel snag was not reported when dy exceeded 15 in. because the post was considered to be broken.

The results compiled are the maximum quantity for each category for the given model. This implies that for each model, quantities in different categories are not necessarily from the same run within the model, but a combination of the most critical values from all the runs.

These results did not show a distinct point at which one additional failed post would cause the system to drastically fail. However, a four consecutive post failure matched the previous limit that a maximum deflection in excess of 1321 mm (52 in.) was too large, and therefore, system failure was determined to be caused by the fracture or failure of four consecutive posts. Again, the 1321-mm (52-in.) limit could be increased or reduced, but was selected based on engineering judgment because it seemed to be a reasonable limit.

14 SUMMARY AND FULL-SCALE TEST RECOMMENDATION

14.1 Summary

In the study, small diameter Douglas Fir and Ponderosa Pine round wood posts were investigated for use in an MGS guardrail system. The introduction of such a system would open a new product market for the timber industry, help facilitate the cost of removing dangerous forest fire fuels, and serve as an effective and economical alternative to other barrier systems used on today's roadways.

The study began with two rounds of cantilever bogie tests that isolated the behavior and strength of the posts. The objective of the testing was to optimize the diameter of the posts used in the new system, maintaining a careful balance between cost and effectiveness. The determination of the post diameter was based on the strength of the posts and estimated soil resistance from previous post testing. After the first round of testing, the diameter values of 171 mm (6.75 in.) for the Douglas Fir species and 191 mm (7.5 in.) for the Ponderosa Pine species were estimated to be sufficient.

However, following the first round of tests, significant flaws were found in the standard testing methods used in cantilever bogie tests. These flaws had the potential to overestimate post strength by as much as 50 percent due to the effects of inertia, leading to inaccurate and misleading diameter calculations. After identifying the problem, an alternate procedure was investigated with a series of three additional cantilever bogie tests. The tests confirmed the problem and showed that a reduction in bogie impact speed would significantly reduce the inertial effects, leading to a much more accurate prediction of ultimate fiber stress. Unfortunately, the flaws were not identified in time to modify the original diameter calculations as the posts had already been ordered, but the adjustments were utilized in the second round of tests.

The second round of cantilever bogie tests was conducted with the reduced bogie impact speed. When the tests were completed, a diameter range was chosen for each species to proceed with soil tests. The target diameter values were 165 mm (6.5 in.) for Douglas Fir and 184 mm (7.25 in.) for Ponderosa Pine, both with an acceptable range of 6 mm (0.25 in.) below and 19 mm (0.75 in.) above the target. The second round of cantilever tests was also used to develop a grading criterion for the two species. The grading criterion was based on the population distribution of knots and ring density. It needed to be tight enough to reduce the diameter of the posts as much as possible, but relaxed enough to allow a high percentage of the posts to qualify. Bogie soil tests were conducted to verify these results.

The initial soil bogie tests showed that the estimated soil resistance force was 20 percent lower than the actual force determined from the testing. Because of this, five of the first six posts tested fractured rather than rotating as desired. Although the embedment of the posts could have been reduced to bring the peak force closer to the optimal 42.3 kN (9.5 kips), such a reduction could also lead to a reduced energy absorption capacity caused by the posts pulling out of the soil. Therefore, it was decided to increase the post diameter and accept a force level that exceeded the optimum level.

Based on the peak resisting force determined from the six initial tests, the target nominal diameter was adjusted to 184 mm (7.25 in.) for Douglas Fir and 203 mm (8.00 in.) for Ponderosa Pine. The acceptable ranges remained at 6 mm (0.25 in.) below the target and 19 mm (0.75 in.) above the target.

A second set of seven bogie tests – three for Douglas Fir and four for Ponderosa Pine – was conducted on posts of the new diameter, this time with six of the posts rotating through the soil and only one fracturing.

For Ponderosa Pine, the final target diameter was 203 mm (8.00 in.), with an acceptable range from 197 mm (7.75 in.) to 222 mm (8.75 in.). The standard deviation for the posts was determined as 8 mm (0.3 in.) from the random population sample. Using Monte Carlo simulation, a 1,000-sample population was developed from these parameters based on a normal distribution. Once the size distribution was developed, a second simulation was completed to develop an MOR for each of the generated post diameters. These two models were combined with elastic bending equations to determine the peak force capacity for each of the generated samples. Once this was determined, the average peak force and standard deviation was determined and used to determine the percentage of the posts falling below the 58-kN (13-kip) requirement.

For the target diameter, the average peak force was determined as 69.6 kN (15.64 kips) with a standard deviation of 18.2 kN (4.09 kips). This resulted in a 26 percent chance of post failure, falling below the desired limit. For the mid-range diameter of 210 mm (8.25 in.), the average was 76.3 kN (17.15 kips) with a standard deviation of 19.8 kN (4.45 kips), lowering the probability of failure to 18 percent. Based on these calculations, the probability that the entire system may fail due to four consecutive posts failing is somewhere between 0.1 and 0.5 percent.

It should be noted that this determination is not the probability that the system will fail, but the probability that four consecutive posts will fail when impacted under the

NCHRP Report 350 Test Designation 3-11 criteria. This four post failure would in turn lead to a deflection exceeding the maximum allowable deflection of 1321 mm (52 in.).

The actual failure probability for the entire system under such impact conditions would depend on the probability of failure for the rail, the anchors, the bolts, and all other parts of the system. These parts were not considered in the failure calculations because the research focused on the behavior of the posts.

Additionally, the probability that the system would fail when installed along roadways across the country would depend on soil and impact severity variations. As stated previously, the criteria set forth in NCHRP Report 350 Test Designation 3-11 for soil and impact conditions represent a "worst practical condition." In Report 350, the impact speed and angle have been selected near the 85th percentile of all ran-off-road passenger vehicle accidents, the test vehicles have been chosen as 5th and 95th percentile vehicle weights, and the impact location has been specified as the location most likely to result in failure. Combining these factors shows that the vast majority of actual vehicular impacts with the guardrail system will be less severe than the tested case.

The same Monte Carlo procedure was followed for Douglas Fir which had a final target diameter of 184 mm (7.25 in.), with an acceptable range from 178 mm (7.0 in.) to 203 mm (8.0 in.). The standard deviation for the Douglas Fir post diameter was 5 mm (0.2 in.). An average peak force of 65.2 kN (14.65 kips) with a standard deviation of 9.5 kN (2.14 kips) was determined for the target diameter, and an average of 72.1 kN (16.2 kips) with a standard deviation of 10.5 kN (2.36 kips) was determined for the mid-range diameter. The probability of a post falling below the 53.4 kN (12 kip) limit was 12.2 percent for the target diameter and 3.2 percent for the mid-range diameter. This meant the probability of the system failing due to four consecutive failed posts was less than a tenth of a percent in both cases.

Because the probability of post failure was so much lower for Douglas Fir than for Ponderosa Pine, the effects of reducing the Douglas Fir target post diameter were investigated by generating another force capacity model. The model used a decreased mean diameter value of 178 mm (7.00 in.) and determined an average peak load of 58.3 kN (13.1 kips) with a standard deviation of 8.5 kN (1.90 kips). This distribution resulted in a 27.6 percent chance that any one given post would have a capacity less than the 53.4 kN (12-kip) limit, well below the 40 percent limit. Reducing the diameter further would result in a chance of failure exceeding that limit. With the decreased diameter, the probability that the system would fail due to four consecutive failed posts increased to 0.6 percent, which was still less than the 3-percent limit.

14.2 Future Work

Two full-scale crash tests are recommended, one for each species. The full-scale crash tests should be used to verify the results found herein and validate the system to the NCHRP Report No. 350 standards.

Two factors, target diameter and grading criteria, need to be considered in the final recommendation. The grading criteria for the posts used in the full-scale tests should meet the grading criteria established for each species. Since the grading criteria are based on the population of the production line, meaning that the vast majority of the posts leaving the manufacturing line will exceed these criteria, no effort should be made to select posts of the lowest possible quality. In selecting a target diameter and range, more care should be taken.

When producers fill a post order, they will select posts fitting the size range from a stock pile on site. Timber producers will attempt to find posts with diameters close to the established target, but will inevitably select any material that falls within the upper and lower bounds of the established range. Therefore, the average diameter of the selected posts will probably fall somewhere between the target and the mid-range of the limits. The standard deviation should be fairly consistent. Knowing this, the probability of failure for a single post will fall between two extremes, that for the target diameter, and that for the mid-range diameter.

In full-scale testing, the more critical of the two cases should be tested, implying that the posts should be selected with a sample average near the target diameter rather than an average near the mid-range diameter.

The recommended grading criteria and diameter ranges for the full-scale tests are presented below for each species. In addition, posts of both species must meet the general grading criteria discussed previously and presented in Appendix H.

14.2.1 Ponderosa Pine

Specific grading criteria for Ponderosa Pine include limitations on knots and ring density. Any knots found on the surface of the post shall be less than or equal to 102 mm (4 in.) in diameter. Ring density should not be less than 6 rings-per-inch as averaged over a 76 mm (3 in.) length. The average diameter for the posts installed for the full-scale test should be about 203 mm (8.00 in.), and all individual post diameters must fall between 197 mm (7.75 in.) and 222 mm (8.75 in.).

14.2.2 Douglas Fir

Douglas Fir grading specifications also include limits on knot size and ring density. For the Douglas Fir species, the maximum allowable knot diameter is 51 mm (2 in.). As with Ponderosa Pine, the ring density of the posts should not be less than 6 rings-per-inch as averaged over a 76 mm (3 in.) length. Based on the reduced diameter probability calculations, the average diameter of the posts installed for the full-scale test should be approximately 178 mm (7.00 in.). Individual post diameters should fall between 171 mm (6.75 in.) and 197 mm (7.75 in.).

14.2.3 System Details

The two full-scale crash tests should be conducted on a standard MGS installation, with the standard steel posts replaced by the round timber posts embedded 940 mm (37 in.), and the rectangular blockouts replaced with special concave blockouts made to fit the posts. All other aspects of the system should remain the same, including all anchor post details, rail mounting height, and post spacing.

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16 APPENDICES

Appendix A. Knot Location Documentation Tables

Table A-1. Knot Locations for Douglas Fir Posts Cantilever Testing Round 1

Post Number	Knot Location: Distance from Top (in.)	Knot Location: CCW from Front (degrees)	Knot Size: Length (in.)	x	Knot Size: Width (in.)	Comments
2	7.750	95	2.0000	x	2.0000	
	24.500	60	0.7500	x	1.5000	
	32.500	35	0.7500	x	0.7500	
	57.875	95	1.5000	x	1.5000	
	24.250	180	1.5000	x	2.0000	
	33.000	140	1.2500	x	1.7500	
	41.500	175	1.5000	x	1.7500	
	50.625	165	0.5000	x	0.5000	
	44.000	160	0.3750	x	0.3750	
	46.750	160	0.3750	x	0.3750	
	68.250	160	1.7500	x	2.5000	
	11.375	230	0.7500	x	0.7500	
	8.375	290	1.2500	x	1.8750	
	25.000	290	0.2500	x	0.2500	
	33.500	270	1.5000	x	1.5000	
	40.000	260	1.5000	x	1.5000	
	57.750	255	1.5000	x	1.5000	
	69.250	260	1.0000	x	1.2500	
	51.000	285	0.5000	x	0.5000	
3				x		NO KNOTS
6	1.375	185	1.2500	x	1.2500	
	1.750	130	1.1250	x	1.1250	
	12.125	170	0.7500	x	0.7500	
	14.125	110	1.2500	x	1.0000	
	2.625	80	1.1250	x	1.1250	
	68.500	145	1.0000	x	1.2500	
	58.875	135	0.7500	x	0.7500	
	20.625	125	0.2500	x	0.2500	
	22.250	105	1.0000	x	1.0000	
	45.500	100	1.0000	x	1.0000	
	69.125	75	0.7500	x	0.7500	
	67.375	20	0.3750	x	0.3750	
	58.625	20	1.0000	x	1.0000	
	47.000	40	0.6250	x	0.6250	
	44.125	355	0.7500	x	0.7500	
	26.875	10	0.5000	x	0.5000	
	25.000	330	0.7500	x	0.7500	
	25.125	345	0.1875	x	0.1875	
	17.375	25	1.2500	x	1.2500	
	12.938	70	1.0000	x	1.0000	
	21.250	65	0.5000	x	0.5000	
	0.750	20	0.2500	x	0.2500	
	13.250	335	1.5000	x	1.5000	
	69.500	335	1.2500	x	1.2500	
	1.500	270	1.6250	x	1.2500	
	15.375	230	1.5000	x	2.2500	
	43.250	205	0.6250	x	0.6250	
	69.500	205	1.0000	x	1.5000	

Post Number	Knot Location		Knot Size	Comments
	Distance from Top (in.)	CCW from Front (degrees)	Length x Width (in.) (in.)	
9	6.375	20	1.2500 x 1.5000	
	18.375	10	1.0000 x 1.0000	
	6.875	325	0.5625 x 0.6250	
	32.375	335	1.0000 x 1.0000	
	34.125	10	0.3125 x 0.3125	
	30.250	25	0.3750 x 0.3750	
	30.250	45	1.8750 x 1.3750	
	45.875	20	0.6250 x 0.6250	
	61.000	40	1.2500 x 1.3750	
	65.125	80	0.5000 x 0.5000	
	59.750	335	0.7500 x 0.7500	
	44.688	320	0.8125 x 0.6875	
	46.375	270	0.3125 x 0.3125	
	19.375	295	0.3750 x 0.3750	
	32.250	245	0.3750 x 0.3750	
	61.250	225	0.2500 x 0.2500	
	6.125	160	0.8125 x 0.6875	
	59.375	165	0.6250 x 0.6250	
	45.750	145	0.6250 x 0.6250	
	31.875	120	0.7500 x 0.8750	
	19.750	95	1.2500 x 1.7500	
10	12.250	0	1.5000 x 1.2500	
	16.688	20	0.3750 x 0.3750	
	1.375	320	0.1250 x 0.1250	
	20.000	305	2 SMALL KNOTS	
	33.375	10	0.2500 x 0.2500	2 KNOTS
	36.625	50	1.0000 x 1.2500	
	51.375	75	0.7500 x 0.3750	
	44.250	30	0.2500 x 0.3750	
	54.500	25	0.2500 x 0.2500	
	75.250	35	3 SMALL KNOTS	
	75.500	65	0.2500 x 0.2500	
	76.250	100	0.8750 x 1.5000	
	52.500	120	0.7500 x 0.7500	
	34.750	105	0.3750 x 0.3750	
	13.125	95	1.0000 x 1.0000	
	40.250	95	2 SMALL KNOTS	(0.125 IN. AND 0.25 IN.)
	11.375	70	1.7500 x 1.7500	
	10.375	145	0.3125 x 0.3125	
	10.375	135	0.2500 x 0.2500	
	25.500	165	0.2500 x 0.2500	
	1.125	170	0.3750 x 0.5000	
	34.750	170	0.3750 x 0.5000	
	54.500	155	0.3750 x 0.3750	
	73.250	155	0.3750 x 0.3750	2 KNOTS
	65.500	200	0.6250 x 0.7500	
	47.000	200	0.5000 x 0.5000	
	51.125	185	0.3750 x 0.3750	
	51.938	215	1.0000 x 1.0000	
	21.750	205	0.2500 x 0.2500	
	20.375	210	0.1250 x 0.1250	2 KNOTS
	11.938	195	0.7500 x 0.7500	
	11.000	265	1.3750 x 1.7500	
	14.375	285	0.5000 x 0.5000	
	37.625	235	0.8750 x 1.0000	
	42.500	230	0.2500 x 0.2500	
	56.000	265	0.2500 x 0.2500	2 KNOTS
	51.750	300	1.2500 x 1.2500	
	44.250	305	0.3750 x 0.3750	
	38.875	315	0.8750 x 1.0000	
	50.875	345	0.8750 x 0.8750	
	76.250	350	1.1250 x 1.1250	

Post Number	Knot Location: Distance from Top (in.)	Knot Location: CCW from Front (degrees)	Knot Size: Length (in.) x Width (in.)	Comments
11	7.500	155	3 SMALL KNOTS	
	9.000	85	2.5000 x 3.5000	
	5.500	80	5.0000 x 1.2500	GOUGE
	7.750	85	1.2500 x 1.2500	
	17.750	125	2.0000 x 2.0000	
	32.250	125	0.7500 x 0.7500	
	22.250	160	2.0000 x 2.5000	
	43.000	150	1.7500 x 2.5000	
	50.750	140	0.2500 x 0.2500	
	54.750	150	0.2500 x 0.2500	
	62.250	135	2.0000 x 2.0000	
	67.375	170	0.2500 x 0.2500	
	46.000	120	2.0000 x 2.0000	
	59.000	85	1.0000 x 1.5000	
	61.000	45	0.3750 x 0.3750	
	42.500	45	0.6250 x 0.6250	Grain distortion from 40 deg. to 80 deg. about 39 in down.
	8.500	340	1.7500 x 2.0000	
	5.750	330	0.6250 x 0.6250	
	14.250	320	1.2500 x 2.0000	
	13.625	300	0.7500 x 0.7500	
	28.875	325	1.0000 x 1.5000	
	53.500	350	1.0000 x 2.0000	
	62.750	320	2.2500 x 2.0000	
	44.250	295	1.2500 x 1.5000	
	53.000	285	0.7500 x 0.7500	
	22.750	265	1.7500 x 2.2500	
	69.750	235	2.0000 x 2.0000	
	45.500	235	0.4375 x 0.4375	
	6.500	235	0.5000 x 0.5000	
	7.125	225	0.2500 x 0.2500	
13	11.125	5	0.2500 x 0.2500	
	8.875	305	1.5000 x 1.7500	
	22.500	330	2.0000 x 1.2500	
	36.125	345	1.5000 x 1.5000	
	49.875	355	2.0000 x 1.5000	
	53.500	0	0.6250 x 0.6250	
	71.000	0	1.5000 x 1.5000	
	58.875	15	0.3750 x 0.3750	
	39.125	25	1.0000 x 1.0000	
	6.750	40	1.0000 x 1.0000	
	73.625	45	1.2500 x 1.5000	
	75.625	330	1.2500 x 1.2500	
	73.625	60	0.2500 x 0.2500	
	22.750	75	1.3750 x 1.7500	
	36.500	100	1.3750 x 1.7500	
	40.000	100	0.5000 x 0.5000	
	50.625	100	1.5000 x 1.5000	
	70.875	120	1.5000 x 2.0000	
	43.250	125	0.2500 x 0.2500	
	56.625	125	0.3750 x 0.3750	
	53.000	145	1.5000 x 1.7500	
	21.875	165	1.5000 x 2.0000	
	5.500	115	1.1250 x 1.1250	
	8.750	115	0.7500 x 0.7500	
	27.250	175	0.3750 x 0.3750	
	14.125	185	0.2500 x 0.2500	
	74.250	175	1.5000 x 1.5000	
	37.000	210	1.2500 x 2.0000	
	top	185	2.0000 x 2.0000	
	9.125	200	0.8750 x 0.8750	
	21.625	245	1.5000 x 2.0000	
	5.750	280	1.2500 x 1.2500	
	25.250	280	1.2500 x 1.2500	
	40.000	280	1.7500 x 1.7500	
	52.000	275	1.5000 x 1.5000	
	59.125	260	0.7500 x 1.1250	
	9.250	315	1.0000 x 1.0000	

Post Number	Knot Location		Knot Size			Comments
	Distance from Top	CCW from Front	Length	x	Width	
	(in.)	(degrees)	(in.)		(in.)	
15	16.375	215	1.0000	x	1.0000	
	23.500	225	0.6250	x	0.6250	
	30.250	190	1.0000	x	1.0000	
	42.125	200	0.8750	x	0.8750	
	47.875	230	0.6250	x	0.6250	
	75.500	175	1.2500	x	1.2500	
	48.500	145	1.7500	x	1.7500	
	7.125	155	0.2500	x	0.2500	
	9.688	140	0.2500	x	0.2500	
	54.750	120	1.5000	x	1.5000	
	43.250	100	1.7500	x	2.2500	
	23.500	110	2.0000	x	2.2500	
	16.250	55	1.7500	x	2.0000	
	48.500	40	1.6250	x	2.1250	
	bottom	60	0.7500	x	0.7500	
	55.750	35	0.5000	x	0.5000	
	60.000	345	0.5000	x	0.5000	
	30.375	0	1.0625	x	1.0625	
	27.500	325	0.7500	x	0.7500	
	0.625	330	0.8750	x	0.8750	
	3.000	227	0.7500	x	0.7500	
	9.625	290	0.6250	x	0.6250	
	20.125	295	0.5000	x	0.5000	
	30.500	270	0.7500	x	0.7500	
	36.750	245	0.2500	x	0.2500	
18	2.750	60	0.2500	x	0.2500	
	19.500	355	1.0000	x	1.0000	
	18.375	305	1.8750	x	1.5000	
	50.875	310	1.7500	x	1.2500	
	66.250	290	1.5000	x	1.7500	
	51.625	5	0.5625	x	0.6875	
	67.375	25	0.3750	x	0.3750	
	18.000	60	0.5000	x	0.6250	
	69.125	75	0.3750	x	0.3750	
	51.625	115	0.4375	x	0.4375	
	66.750	150	0.6250	x	0.6250	
	21.375	175	0.8750	x	1.0000	
	68.500	180	0.8750	x	0.8750	
	66.375	200	3 SMALL KNOTS			
	69.000	200	0.2500	x	0.2500	
	39.375	200	1.5000	x	2.0000	
	18.375	230	1.8750	x	1.8750	
	38.500	270	1.5000	x	2.0000	
	52.125	225	1.2500	x	1.5000	
	59.250	215	0.3750	x	0.3750	

Post Number	Knot Location		Knot Size	Comments
	Distance from Top (in.)	CCW from Front (degrees)	Length x Width (in.) (in.)	
20	73.750	270	1 SMALL KNOT	
	74.250	240	1 SMALL KNOT	
	21.000	15	5.7500 x 2.0000	
	15.125	20	0.3750 x 0.3750	
	24.750	10	0.7500 x 0.7500	
	31.500	55	0.3750 x 0.3750	
	35.625	50	0.5000 x 0.5000	
	77.250	10	0.2500 x 0.2500	
	51.688	0	0.3125 x 0.3125	
	77.000	320	1.0000 x 1.0000	
	62.125	285	0.3750 x 0.3750	
	41.750	330	0.3750 x 0.3750	
	14.875	295	0.3750 x 0.3750	
	27.750	295	0.5000 x 0.5000	
	39.000	295	0.5000 x 0.5000	
	1.375	230	0.5000 x 0.6250	
	15.125	205	1.2500 x 1.2500	
	26.875	205	1.2500 x 1.2500	
	39.625	185	1.5000 x 1.5000	
	71.750	195	1.6250 x 1.6250	
	76.000	145	1.5000 x 1.7500	
	50.750	165	2.0000 x 2.0000	
	28.375	125	0.5000 x 0.5000	
	14.500	120	1.5000 x 1.5000	
	14.000	95	0.3750 x 0.3750	
	TOP	130	1.3750 x 1.1250	GOUGE
	38.625	105	1.7500 x 2.0000	
	51.375	90	1.5000 x 2.0000	
	75.000	100	1.5000 x 2.0000	
	51.000	70	0.5000 x 0.5000	
	top	60	2.0000 x 2.0000	
22	12.750	285	0.7500 x 0.7500	
	35.750	275	1.1250 x 1.1250	
	37.875	315	0.6250 x 0.6250	
	60.750	265	1.1250 x 1.1250	
	33.625	345	1.0000 x 1.0000	
	60.875	15	1.0000 x 1.0000	
	64.625	45	0.1875 x 0.1875	
	47.750	55	0.1250 x 0.1250	
	39.250	25	0.2500 x 0.2500	
	11.250	25	1.0000 x 1.0000	
	34.375	65	1.1250 x 1.1250	
	14.750	95	0.7500 x 0.7500	
	9.500	105	1.5000 x 1.5000	
	60.250	90	1.0000 x 1.0000	
	50.000	90	0.3750 x 0.3750	
	36.500	125	1.1250 x 1.1250	
	70.750	150	0.2500 x 0.2500	
	11.750	190	1.1250 x 1.1250	
	9.625	220	1.1250 x 1.1250	
	34.500	195	1.1250 x 1.1250	
	61.625	170	1.1250 x 1.1250	
	59.500	225	1.1250 x 1.1250	
	42.375	210	0.2500 x 0.2500	
	70.000	235	0.2500 x 0.2500	

Post Number	Knot Location		Knot Size		Comments
	Distance from Top (in.)	CCW from Front (degrees)	Length (in.)	x Width (in.)	
24	3.250	345	0.3750	x 0.3750	
	9.125	0	0.3750	x 0.3750	
	13.625	350	0.2500	x 0.2500	
	25.750	310	0.7500	x 1.0000	
	2.125	280	0.7500	x 0.7500	
	11.750	285	0.2500	x 0.2500	
	33.750	250	0.7500	x 0.7500	
	39.938	300	0.1250	x 0.1250	
	45.500	300	1.0000	x 1.0000	
	74.250	290	0.5000	x 0.5000	
	48.000	320	0.3750	x 0.3750	
	76.250	45	0.5000	x 0.5000	
	47.000	75	0.7500	x 0.7500	
	40.500	95	0.1250	x 0.1250	
	28.250	85	0.6250	x 0.6250	
	29.375	135	1.3750	x 1.3750	
	25.250	90	1.2500	x 1.5000	
	2.125	75	1.0000	x 1.0000	
	5.875	105	0.3750	x 0.3750	
	73.875	150	1.5000	x 2.0000	
	46.125	175	1.3750	x 1.5000	
	2.625	180	2.0000	x 1.2500	
	76.500	210	1.5000	x 1.5000	
	69.000	195	0.1875	x 0.1875	
	40.000	320	0.1250	x 0.1250	
	17.375	210	0.2500	x 0.2500	
	4.750	215	0.6250	x 0.6250	
	10.750	225	0.1250	x 0.1250	
25	1.875	315	2.0000	x 2.5000	
	0.250	220	1.5000	x 1.5000	
	14.375	295	1.7500	x 2.2500	
	31.500	305	0.5000	x 0.5000	
	41.750	280	1.7500	x 2.2500	
	55.250	325	1.8750	x 1.5000	
	65.750	355	1.0000	x 1.0000	
	75.375	320	1.5000	x 1.5000	
	70.250	295	0.3750	x 0.3750	
	64.500	260	1.7500	x 2.0000	
	31.000	240	0.2500	x 0.2500	
	56.750	240	0.7500	x 0.7500	
	76.500	205	0.3750	x 1.0000	
	28.250	215	1.6250	x 1.8750	
	14.750	210	1.0000	x 1.0000	
	41.000	195	1.7500	x 2.2500	
	36.000	200	0.2500	x 0.2500	
	19.250	140	1.0000	x 1.0000	
	55.375	145	1.7500	x 2.0000	
	64.375	145	1.2500	x 1.2500	
	73.875	160	1.7500	x 1.7500	
	66.375	95	0.2500	x 0.2500	
	2.000	100	0.7500	x 0.7500	
	14.125	105	1.2500	x 1.2500	
	28.250	95	1.0000	x 1.0000	
	32.688	145	0.2500	x 0.2500	
	43.500	70	1.2500	x 1.2500	
	56.000	60	0.6250	x 0.6250	
	75.500	60	1.0000	x 1.0000	
	30.500	30	1.0000	x 1.0000	
	14.250	25	1.2500	x 1.2500	

Post Number	Knot Location		Knot Size			Comments
	Distance from Top	CCW from Front	Length	x	Width	
	(in.)	(degrees)	(in.)		(in.)	
26	23.875	0	0.1250	x	0.5000	
	45.875	35	0.2500	x	0.2500	
	66.500	25	1.5000	x	1.5000	
	36.875	345	0.6250	x	1.2500	
	44.875	325	1.3750	x	1.6250	
	23.750	285	1.5000	x	1.5000	
	52.250	265	0.5000	x	0.7500	
	66.625	235	1.2500	x	1.5000	
	45.625	195	1.1250	x	1.3750	
	76.500	155	0.2500	x	0.2500	
	62.000	135	0.3750	x	0.3750	
	43.625	130	0.5000	x	0.5000	
	58.313	140	0.2500	x	0.2500	
	34.750	175	0.2500	x	0.2500	
	23.625	180	0.7500	x	0.7500	
	24.875	145	0.5000	x	0.5000	
	36.250	120	0.2500	x	0.2500	
	22.250	90	0.3750	x	0.3750	
	67.500	115	1.0000	x	0.7500	
27	5.000	320	1.3750	x	1.3750	
	10.875	340	0.4375	x	0.4375	
	18.000	0	0.2500	x	0.2500	
	26.250	310	0.7500	x	1.0000	
	42.250	0	0.2500	x	0.2500	
	49.125	0	1.0000	x	1.0000	
	71.750	340	1.2500	x	1.5000	
	56.250	305	0.3750	x	0.3750	
	63.000	315	0.2500	x	0.2500	
	50.250	295	1.0000	x	1.0000	
	38.500	275	0.3750	x	0.3750	
	71.500	255	0.6250	x	0.6250	
	49.125	240	0.7500	x	0.7500	
	7.500	250	0.7500	x	0.7500	
	27.500	220	1.2500	x	1.0000	
	72.500	195	1.0000	x	1.2500	
	5.375	165	1.0000	x	1.0000	
	23.750	170	0.8750	x	1.0000	
	26.750	90	1.5000	x	1.2500	
	34.750	105	0.3750	x	0.3750	
	50.750	105	1.2500	x	1.2500	
	71.250	95	1.5000	x	1.5000	
	56.750	105	0.2500	x	0.2500	
	5.875	45	2.2500	x	1.5000	
	23.500	15	2.0000	x	3.0000	
	49.625	45	1.2500	x	1.7500	

Table A-2. Douglas Fir Length and Circumference Measurement

	Length (in.)	Avg. Length (in.)	Circumference (in.)		
			Location	Critical Zone	Critical Zone Average
Douglas Fir	78.250	78.250	Top	22.875	23.083
	78.250		Mid-length	22.875	
	78.250		Bottom	23.500	
	77.938	77.958	Top	22.625	22.542
	77.938		Mid-length	22.375	
	78.000		Bottom	22.625	
	77.125	77.083	Top	23.125	22.958
	77.063		Mid-length	22.875	
	77.063		Bottom	22.875	
	78.000	78.000	Top	22.875	22.917
	77.938		Mid-length	22.750	
	78.063		Bottom	23.125	
	78.063	78.042	Top	22.875	23.042
	78.000		Mid-length	23.000	
	78.063		Bottom	23.250	
	78.063	78.042	Top	23.125	23.083
	78.000		Mid-length	23.000	
	78.063		Bottom	23.125	
	77.500	77.521	Top	23.000	22.958
	77.500		Mid-length	22.625	
	77.563		Bottom	23.250	
	78.000	78.000	Top	22.750	22.833
	78.000		Mid-length	22.750	
	78.000		Bottom	23.000	
	78.000	78.000	Top	22.625	22.667
	78.000		Mid-length	22.500	
	78.000		Bottom	22.875	
	78.000	78.000	Top	23.125	22.833
	78.000		Mid-length	22.625	
	78.000		Bottom	22.750	
	77.938	77.917	Top	23.250	23.208
	77.938		Mid-length	23.000	
	77.875		Bottom	23.375	
	77.438	77.438	Top	22.500	22.542
	77.438		Mid-length	22.250	
	77.438		Bottom	22.875	
	77.750	77.750	Top	23.625	23.583
	77.750		Mid-length	23.375	
	77.750		Bottom	23.750	
	77.375	77.375	Top	23.250	23.000
	77.375		Mid-length	22.875	
	77.375		Bottom	22.875	
	77.500	77.500	Top	22.875	23.125
	77.500		Mid-length	23.125	
	77.500		Bottom	23.375	

*Critical Zone Measurement Locations:

Top – 57 in. from bottom

Mid-length – 39 in. from bottom

Bottom – 21 in. from bottom.

Table A-3. Douglas Fir Pre-test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume (in.^{3})	Density (lb/in.^{3})	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Douglas Fir	2	55	78.250	23.083	22.625	23.500	3308	0.0166	30	25	43	9.67
	3	63	77.958	22.542	22.875	22.750	3175	0.0198	51,26	45,28	54,30	25.67
	6	58	77.083	22.958	23.000	22.375	3252	0.0178	23	22	24	8.00
	9	59	78.000	22.917	22.625	23.375	3267	0.0181	26	26	24	14.33
	10	60	78.042	23.042	22.500	22.750	3264	0.0184	21	20	31	7.00
	11	55	78.042	23.083	22.625	23.000	3287	0.0167	22	33	22	19.33
	13	62	77.521	22.958	22.750	23.000	3267	0.0190	43	30	51	8.33
	15	71	78.000	22.833	22.875	23.125	3249	0.0219	45	39	50	11.00
	18	50	78.000	22.667	22.250	22.375	3163	0.0158	27	26	31	10.00
	20	56	78.000	22.833	22.750	22.875	3236	0.0173	21	23	25	13.00
	22	46	77.917	23.208	23.500	23.000	3348	0.0137	30	26	32	5.33
	24	63	77.438	22.542	23.125	22.500	3177	0.0198	34	28	32	5.33
	25	63	77.750	23.583	23.500	23.500	3447	0.0183	50	53	45	7.33
	26	56	77.375	23.000	23.000	22.250	3256	0.0172	55	27	48	6.33
	27	49	77.500	23.125	23.125	22.875	3310	0.0148	22	30	25	6.00

Table A-4. Knot Locations for Ponderosa Pine Posts Cantilever Testing Round 1

Post Number	Knot Location: Distance from Top (in.)	Knot Location: CCW from Front (degrees)	Knot Size: Length (in.)	x	Knot Size: Width (in.)	Comments
101	1.750	55	2.0000	x	2.3750	
	2.750	0	0.6250	x	0.6250	
	15.500	25	0.8750	x	0.8750	
	29.375	10	1.3750	x	1.5000	
	45.125	345	2.0000	x	2.3750	
	58.500	10	1.3750	x	1.5000	
	68.000	45	1.3750	x	1.5000	
	45.375	85	1.5000	x	1.6250	
	29.500	110	1.1250	x	1.1250	
	16.063	125	1.1250	x	1.1250	
	47.625	125	1.0000	x	1.0000	
	59.750	155	0.5000	x	0.5000	
	69.000	140	0.4375	x	0.4375	
	TOP	145	2.0000	x	2.0000	
	TOP	230	1.7500	x	1.7500	
	13.875	225	2.0000	x	2.0000	
	30.500	170	0.5000	x	0.5000	
	43.750	250	2.2500	x	2.5000	
	30.375	280	0.5000	x	0.5000	
	16.063	300	0.2500	x	0.2500	
	58.875	275	0.6250	x	0.6250	
	67.500	285	1.8750	x	2.0000	
	0.750	310	1.5000	x	1.5000	
104	TOP	90	1.5000	x	1.5000	
	3.500	65	0.3750	x	0.3750	
	3.625	60	0.3750	x	0.3750	
	9.625	20	1.5000	x	1.5000	
	22.375	80	1.1250	x	1.5000	
	47.125	50	0.2500	x	0.2500	
	49.250	70	2.2500	x	3.2500	
	60.250	40	1.2500	x	1.2500	
	68.000	110	3.0000	x	2.5000	
	7.750	140	1.6250	x	1.2500	
	25.750	145	0.5000	x	0.5000	
	37.438	125	2.0000	x	1.7500	
	53.063	165	0.6250	x	0.6250	
	2.500	200	0.7500	x	0.7500	
	21.500	200	3.3750	x	2.2500	
	12.000	250	0.3125	x	0.3125	
	37.500	260	3.7500	x	2.6250	
	62.000	265	0.8750	x	0.8750	
	71.625	245	0.2500	x	0.2500	
	51.000	305	1.0000	x	1.0000	
	25.313	310	0.6250	x	0.6250	
	8.625	315	2.0000	x	2.0000	
	25.000	10	0.6875	x	0.6875	
	39.250	350	1.0000	x	1.0000	
	70.000	355	1.0000	x	1.0000	

Post Number	Knot Location		Knot Size	Comments
	Distance from Top (in.)	CCW from Front (degrees)	Length x Width (in.) x (in.)	
105	3.500	135	0.7500 x 0.8750	
	1.375	120	1.1250 x 1.1250	
	19.125	110	0.5000 x 0.5000	
	3.250	20	1.5000 x 2.0000	
	37.500	180	1.2500 x 2.0000	
	54.000	205	2.2500 x 3.7500	
	51.313	100	1.0000 x 1.1250	
	24.125	25	3.0000 x 1.1250	
	25.875	30	1.0000 x 1.6250	GOUGE
	21.250	10	0.1875 x 0.1875	
	21.125	35	0.2500 x 0.2500	
	22.688	50	0.2500 x 0.2500	
	34.500	60	0.3125 x 0.3125	
	70.000	30	2.0000 x 2.5000	
	70.750	0	0.5000 x 0.5000	
	72.000	340	1.7500 x 3.0000	
	22.000	260	0.5000 x 0.5000	
	18.125	270	0.5000 x 0.5000	
	23.500	255	1.0000 x 1.0000	
	38.000	260	1.2500 x 1.7500	
	70.750	250	1.7500 x 3.0000	
	52.250	300	1.0000 x 1.5000	
	20.125	320	1.5000 x 1.5000	
	BOTTOM	360	x 5.5000	GOUGE
	BOTTOM		4.0000 x 5.0000	GOUGE (0.75 in. deep)
	26.000		4.5000 x 5.0000	GOUGE (0.5 in. deep)
106	68.125	100	0.2500 x 0.2500	
	75.750	85	0.8750 x 0.8750	
	0.500	115	0.4375 x 0.4375	
	11.125	100	0.5000 x 0.5000	
	25.000	115	0.5000 x 0.5000	
	26.750	110	0.5000 x 0.5000	
	27.500	75	1.5000 x 1.0000	
	44.125	65	1.5000 x 1.2500	
	6.875	50	0.7500 x 0.7500	
	27.375	25	0.8750 x 0.8750	
	71.875	25	2.0000 x 2.7500	
	TOP	0	5.0000 x 3.0000	
	43.750	280	2.0000 x 2.0000	
109	14.750	135	1.5000 x 1.7500	
	30.750	155	1.2500 x 1.3750	
	43.250	90	1.8750 x 2.1250	
	56.125	65	1.0000 x 1.0000	
	70.000	70	0.3750 x 0.3750	
	68.875	135	1.2500 x 1.2500	
	45.000	150	1.5000 x 1.5000	
	64.750	185	2.7500 x 1.7500	
	15.875	215	1.0000 x 1.1250	
	29.875	235	1.2500 x 1.3750	
	44.125	235	1.1250 x 1.2500	
	65.250	250	1.2500 x 1.0000	
	56.250	275	1.0625 x 1.2500	
	15.375	285	1.3750 x 1.6250	
	68.375	290	0.8750 x 0.8750	
	45.000	370	1.1250 x 1.1250	
	29.750	345	1.2500 x 1.5000	
	55.500	350	2.0000 x 1.3750	
	45.250	20	1.0000 x 1.0000	
	16.188	5	1.0625 x 1.0625	
	4.000	35	2.0000 x 2.0000	GOUGE

Post Number	Knot Location		Knot Size			Comments
	Distance from Top	CCW from Front	Length	x	Width	
	(in.)	(degrees)	(in.)		(in.)	
111	27.875	95	0.5000	x	0.5000	
	54.750	100	1.0000	x	1.0000	
	61.625	90	0.5625	x	0.5625	
	61.000	195	1.0000	x	1.3750	
	39.000	230	1.0000	x	1.0000	
	21.750	245	0.6875	x	0.6875	
	70.500	245	0.7500	x	0.7500	
	52.625	280	0.2500	x	0.2500	
	14.125	280	0.3750	x	0.3750	
112	3.563	40	0.2500	x	0.2500	
	9.813	20	0.2500	x	0.2500	
	24.750	20	0.2500	x	0.2500	
	31.125	80	0.3125	x	0.3125	
	18.438	90	0.3750	x	0.3750	
	24.375	110	0.5000	x	0.5000	
	5.375	115	0.2500	x	0.2500	
	9.000	140	0.5000	x	0.5000	
	1.500	175	0.7500	x	1.0000	
	39.500	165	0.5000	x	0.5000	
	52.375	165	0.3125	x	0.3125	
	49.000	225	0.3125	x	0.3125	
	18.688	225	0.3750	x	0.3750	
	24.750	230	0.3750	x	0.3750	
	30.875	205	0.3750	x	0.3750	
	8.250	260	0.5625	x	0.5625	
	48.500	320	0.3750	x	0.3750	
117	1.750	55	0.7500	x	1.0000	
	14.125	45	0.6250	x	0.6250	
	31.250	20	0.5000	x	0.5000	
	24.125	85	0.7500	x	0.7500	
	39.750	25	0.3750	x	0.3750	
	47.000	20	0.6250	x	0.7500	
	69.625	40	0.5000	x	0.5000	
	76.250	45	0.3750	x	0.3750	
	58.750	330	0.4375	x	0.4375	
	68.500	115	0.4375	x	0.4375	
	61.250	90	0.3125	x	0.3125	
	44.375	70	0.5000	x	0.5000	
	39.125	110	0.5625	x	0.5625	
	0.438	115	0.2500	x	0.2500	
	31.500	115	0.3750	x	0.3750	
	48.625	140	0.6250	x	0.6250	
	60.125	175	0.3750	x	0.3750	
	12.750	155	0.8750	x	1.1250	
	17.375	180	0.8750	x	1.1250	
	76.500	140	0.3125	x	0.3125	
	75.625	205	0.3750	x	0.3750	
	68.313	235	0.5625	x	0.5625	
	47.375	190	0.7500	x	1.1250	
	1.000	260	1.2500	x	1.5000	
	28.625	230	0.8750	x	1.2500	
	48.500	255	0.5000	x	0.5000	
	19.500	325	0.3125	x	0.3125	
	2.000	340	0.2500	x	0.2500	

Post Number	Knot Location		Knot Size			Comments
	Distance from Top	CCW from Front	Length	x	Width	
	(in.)	(degrees)	(in.)		(in.)	
118	10.625	350	0.7500	x	0.7500	
	TOP	5	1.2500	x	1.2500	
	26.750	350	0.7500	x	0.7500	
	36.000	0	1.0000	x	1.0000	
	47.500	290	1.2500	x	1.2500	
	37.500	265	1.1250	x	1.1250	
	9.625	245	0.6250	x	0.6250	
	TOP	220	1.2500	x	1.2500	
	28.250	220	1.2500	x	1.2500	
	49.625	205	1.3750	x	1.3750	
	38.000	170	1.2500	x	1.2500	
	9.750	145	0.8750	x	0.8750	
	26.125	105	0.4375	x	0.4375	
	47.500	80	0.5000	x	0.5000	
	77.000	95	0.3750	x	0.3750	
120	23.750	35	0.8750	x	0.8750	
	3.625	75	0.5000	x	0.5000	
	36.500	10	0.3750	x	0.3750	
	39.750	120	0.7500	x	0.7500	
	24.625	135	0.5625	x	0.5625	
	3.000	175	0.7500	x	0.7500	
	17.000	190	0.6250	x	0.6250	
	43.750	185	0.8125	x	0.8125	
	35.688	225	0.5000	x	0.5000	
	40.125	225	0.5000	x	0.5000	
	48.125	235	0.6250	x	0.6250	
	31.500	245	0.6875	x	0.6875	
	57.625	285	0.5625	x	0.5625	
	8.500	310	0.2500	x	0.2500	
	18.063	315	0.3750	x	0.3750	
122	13.500	300	2.0000	x	1.3750	
	21.375	295	0.3750	x	0.3750	
	34.375	310	0.7500	x	0.7500	
	44.500	290	0.5625	x	0.5625	
	53.000	275	1.2500	x	1.5000	
	69.375	290	1.0000	x	1.2500	
	49.625	5	0.6250	x	0.6250	
	65.500	20	0.2500	x	0.2500	
	TOP	60	1.7500	x	1.7500	
	10.000	85	0.2500	x	0.2500	
	36.375	90	2.2500	x	2.2500	
	34.688	95	0.1250	x	0.1250	
	52.750	150	0.1250	x	1.5000	
	23.875	165	1.0000	x	1.3750	
	71.250	175	3.0000	x	1.6250	
	46.500	205	2.0000	x	1.5000	
	43.500	210	0.4375	x	0.4375	
	34.250	230	1.3750	x	1.6250	
	11.750	200	1.3750	x	1.1250	
	10.000	250	0.3750	x	0.3750	
	TOP	255	1.0000	x	1.0000	

Post Number	Knot Location		Knot Size			Comments
	Distance from Top	CCW from Front	Length	x	Width	
	(in.)	(degrees)	(in.)		(in.)	
123	17.625	355	0.6250	x	0.6250	
	5.500	340	3.0000	x	2.1250	
	37.250	20	1.5000	x	1.0000	
	41.000	15	0.2500	x	0.2500	
	46.750	5	2.2500	x	1.5000	
	62.125	25	1.2500	x	1.0000	
	BOTTOM	355	0.6250	x	0.6250	
	77.250	300	0.7500	x	0.7500	
	61.250	300	1.1250	x	1.1250	
	47.375	310	0.8750	x	0.7500	
	35.625	315	2.0000	x	1.2500	
	40.000	275	0.5000	x	0.5000	
	46.375	230	1.5000	x	1.0000	
	63.250	235	0.3750	x	0.3750	
	77.250	215	0.5000	x	0.5000	
	25.750	65	0.4375	x	0.4375	
	17.875	170	1.0000	x	1.2500	
	6.500	165	1.5000	x	1.7500	
	40.875	135	0.3750	x	0.3750	
	77.125	135	1.2500	x	1.2500	
	6.500	85	0.8750	x	0.8750	
	25.875	95	0.5000	x	0.5000	
	62.750	100	0.7500	x	0.7500	
	40.500	75	0.6250	x	0.6250	
124	15.750	65	1.2500	x	1.5000	
	20.000	10	0.5000	x	0.5000	
	26.875	355	0.6250	x	0.6250	
	34.375	5	0.5000	x	0.5000	
	51.375	15	0.5000	x	0.5000	
	61.625	20	0.8750	x	0.8750	
	59.250	65	0.7500	x	0.7500	
	37.000	115	2.2500	x	1.7500	
	59.500	120	1.3750	x	1.3750	
	59.625	145	1.1250	x	1.1250	
	0.500	110	0.3750	x	0.3750	
	2.500	170	0.1250	x	1.0000	
	25.438	170	0.5000	x	0.5000	
	71.000	165	2.2500	x	1.2500	
	14.250	200	1.0000	x	0.8750	
	3.813	230	0.1875	x	0.1875	
	34.250	220	0.6250	x	0.6250	
	65.000	220	2.8750	x	1.5000	
	61.750	250	0.3750	x	0.3750	
	54.500	255	1.2500	x	1.1250	
	BOTTOM	285	1.0000	x	1.0000	
	36.500	305	1.1250	x	1.5000	
	59.750	315	0.2500	x	0.2500	

Post Number	Knot Location		Knot Size	Comments
	Distance from Top	CCW from Front	Length x Width	
	(in.)	(degrees)	(in.) (in.)	
127	10.375	355	0.3125 x 0.3125	
	16.500	320	0.7500 x 0.7500	
	8.313	290	1.6250 x 1.6250	
	2.313	302	0.2500 x 0.2500	
	1.625	232	0.5000 x 0.5000	
	10.000	180	0.2500 x 0.2500	
	1.313	160	0.8750 x 0.8750	
	15.625	175	2.0000 x 2.0000	
	16.250	75	0.3750 x 0.3750	
	8.250	55	0.3125 x 0.3125	
	24.875	55	1.6250 x 2.0000	
	35.125	80	1.2500 x 1.5000	
	55.125	115	1.5000 x 1.5000	
	76.750	160	1.0625 x 1.0625	
	37.938	190	0.1250 x 0.1250	
	46.750	190	0.3750 x 0.3750	
	70.250	210	0.6250 x 0.6250	
	56.563	220	1.0000 x 1.0000	
	25.750	285	1.0000 x 1.0000	
	38.250	260	1.0000 x 0.2500	
	42.000	275	3.0000 x 1.7500	
	55.438	320	1.6250 x 1.5000	
	70.000	330	0.2500 x 0.2500	
	46.750	10	0.6250 x 0.6250	
	56.625	45	0.3125 x 0.3125	
	TOP	30	0.7500 x 0.7500	
	BOTTOM	85	0.7500 x 0.7500	
	69.500	130	0.2500 x 0.2500	
	70.250	120	0.2500 x 0.2500	
128	10.500	30	5.0000 x 2.7500	
	11.813	50	0.1250 x 0.1250	
	13.250	85	0.3750 x 0.3750	
	26.250	40	2.0000 x 2.0000	GOUGE
	4.000	345	2.0000 x 2.1250	
	20.000	345	0.6250 x 0.6250	
	38.125	345	2.0000 x 1.6250	
	51.000	350	2.5000 x 1.8750	
	68.000	20	2.0000 x 6.0000	GOUGE
	71.625	15	0.7500 x 0.7500	
	63.500	45	1.5000 x 1.7500	
	20.375	70	0.6250 x 0.6250	
	37.125	60	1.7500 x 2.2500	
	49.500	100	1.3750 x 2.0000	
	4.875	105	1.6250 x 2.0000	
	66.750	120	0.7500 x 0.7500	
	71.125	120	0.6250 x 0.6250	
	37.750	135	0.8750 x 1.1250	
	43.000	180	7.7500 x 1.0000	GOUGE
	26.500	145	1.0000 x 0.7500	
	7.250	170	0.1250 x 0.1250	
	12.000	170	0.2500 x 0.2500	
	19.375	180	0.3750 x 0.3750	
	37.375	200	1.0000 x 1.0000	
	47.500	170	0.2500 x 0.2500	
	62.625	205	0.1250 x 0.8750	
	70.250	210	0.5000 x 0.5000	
	49.500	225	1.0000 x 1.2500	
	67.375	230	1.1250 x 1.1250	
	61.750	250	0.6250 x 0.6250	
	20.625	265	1.5000 x 1.2500	
	27.000	265	1.5000 x 1.6250	
	13.000	280	0.6250 x 0.5000	
	47.875	290	0.5000 x 0.5000	
	63.375	310	2.0000 x 1.3750	
	17.875	345	0.1250 x 0.1250	

Table A-5. Ponderosa Pine Length and Circumference Measurements

	Length (in.)	Avg. Length (in.)	Circumference (in.)		
			Location	Critical Zone	Critical Zone
Ponderosa Pine	77.938	77.979	Top	25.750	25.958
	77.938		Mid-length	26.000	
	78.063		Bottom	26.125	
	78.125	78.042	Top	27.750	28.250
	78.000		Mid-length	28.500	
	78.000		Bottom	28.500	
	78.000	78.042	Top	28.125	27.708
	78.000		Mid-length	27.625	
	78.125		Bottom	27.375	
	78.000	77.875	Top	28.125	27.917
	78.000		Mid-length	28.000	
	77.625		Bottom	27.625	
	78.000	78.000	Top	25.875	26.333
	78.000		Mid-length	26.375	
	78.000		Bottom	26.750	
	78.000	78.000	Top	27.500	27.792
	78.000		Mid-length	27.875	
	78.000		Bottom	28.000	
	78.000	78.000	Top	27.750	28.083
	78.000		Mid-length	28.125	
	78.000		Bottom	28.375	
	78.000	78.083	Top	27.750	27.917
	78.125		Mid-length	27.875	
	78.125		Bottom	28.125	
	78.000	77.938	Top	28.125	28.125
	77.813		Mid-length	28.125	
	78.000		Bottom	28.125	
	78.000	78.021	Top	27.375	27.708
	78.000		Mid-length	27.750	
	78.063		Bottom	28.000	
	78.063	78.063	Top	28.125	28.417
	78.063		Mid-length	28.375	
	78.063		Bottom	28.750	
	78.000	78.000	Top	25.000	25.333
	78.000		Mid-length	25.125	
	78.000		Bottom	25.875	
	78.063	78.042	Top	27.500	27.833
	78.000		Mid-length	27.625	
	78.063		Bottom	28.375	
	78.063	78.021	Top	27.500	27.750
	78.000		Mid-length	27.625	
	78.000		Bottom	28.125	
	78.000	78.000	Top	26.250	25.833
	78.000		Mid-length	25.750	
	78.000		Bottom	25.500	

*Critical Zone Measurement Locations:

Top – 57 in. from bottom
Mid-length – 39 in. from bottom
Bottom – 21 in. from bottom.

Table A-6. Ponderosa Pine Pre-test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume (in.^{3})	Density (lb/in.^{3})	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Ponderosa Pine	101	77	77.979	25.958	26.125	26.000	4191	0.0184	20	19	19	6.00
	104	119.5	78.042	28.250	27.750	28.125	4923	0.0243	22	19	23	5.67
	105	115	78.042	27.708	27.375	27.500	4742	0.0243	19	16	26	7.33
	106	73	77.875	27.917	28.125	27.375	4822	0.0151	32,21	33,19	29,18	5.67
	109	81	78.000	26.333	25.625	28.125	4355	0.0186	20	18	17	5.00
	111	105	78.000	27.792	27.750	27.750	4790	0.0219	19	19	22	14.00
	112	112	78.000	28.083	27.000	28.125	4847	0.0231	23	19	19	25.00
	117	77	78.083	27.917	27.625	27.500	4805	0.0160	20	22	18	18.33
	118	102	77.938	28.125	27.500	28.000	4875	0.0209	19	20	19	9.33
	120	128	78.021	27.708	27.500	27.750	4758	0.0269	20	19	22	12.67
	122	110	78.063	28.417	30.375	27.750	5078	0.0217	21	19	23	11.00
	123	75	78.000	25.333	27.125	26.250	4104	0.0183	23	20	16	11.67
	124	99	78.042	27.833	27.875	28.250	4832	0.0205	22	23	19	16.67
	127	116	78.021	27.750	27.500	28.000	4781	0.0243	25	22	28	13.00
	128	83	78.000	25.833	27.375	25.375	4192	0.0198	16	15	16	10.67

Table A-7. Knot Locations for Douglas Fir Posts Cantilever Testing Round 2

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
401	14.75	0	0.5	
401	42.5	10	0.25	
401	61	10	1.5	
401	23.75	55	1	
401	10.25	60	0.25	2 (.125") knots
401	31.5	60	1.5	
401	45.25	70	0.25	
401	5	90	0.25	
401	57.75	90	1.25	
401	12	120	0.5	
401	17	160	1	
401	40	170	0.25	
401	41	170	0.25	
401	48	170	0.25	
401	57.25	180	1	
401	26	200	1.25	2(.25") knots
401	8	230	0.75	
401	12	240	0.5	
401	52.25	270	0.5	
401	22.25	290	1.5	
401	31.5	310	1.5	
401	45.5	310	0.25	
401	11.75	320	0.75	
401	66	320	1.5	
401	53.75	330	1	gouge (2"x2")
403	37.125	0	1.5	
403	11.375	5	0.625	
403	46.125	5	0.25	
403	20.625	10	0.25	
403	33.125	10	0.375	
403	72	15	0.375	
403	6.375	20	0.25	
403	57	30	0.25	
403	76.25	40	0.25	
403	62.875	45	1.25	
403	0.625	55	0.25	
403	14.625	60	2	
403	32.625	65	0.375	
403	8.5	80	0.625	
403	39	90	2	
403	15.75	105	1.5	
403	59.125	105	0.375	
403	52.375	120	0.25	
403	34.625	125	0.75	
403	13.5	135	1	
403	27.5	160	0.375	
403	11.5	165	1.5	
403	15.75	215	1.25	
403	70	215	0.25	
403	12	220	0.375	
403	52.875	230	0.25	
403	38.5	235	1.25	
403	55.25	255	0.5	
403	70.625	275	0.25	
403	26.375	280	0.375	
403	34.125	285	1.125	
403	10	290	0.375	
403	77.375	300	0.25	
403	15.25	310	1.5	
403	63.875	310	1.25	
403	60	330	1	
403	54.375	340	0.25	

Post Number	Knot Location From Bottom (in.)	Front CCW (Deg.)	Knot Diameter (in.)	Comments:
404	49.375	5	0.375	
404	68.75	15	1.5	
404	39.625	20	0.25	
404	27.75	25	1.25	
404	63.5	30	1.5x1.25	
404	75.75	40	0.25	
404	2.25	45	1.5	
404	11.375	65	0.25	
404	47.75	80	0.75	
404	30.125	90	1.25	
404	22.125	125	0.5	
404	60.5	125	1.25	
404	37.75	130	0.5	
404	48.125	145	0.5	
404	29.25	155	1.25	
404	73.5	165	0.5	
404	36.625	170	1	
404	64.375	175	1.5	
404	17.5	185	1	
404	51	190	1	
404	55.5	190	0.5	
404	3.125	200	0.75	
404	24.625	215	1.25	
404	41.625	235	0.5	
404	30.875	260	2	
404	67.5	260	0.5	
404	60.25	265	2.25x2	
404	75	285	0.5	
404	45.375	295	0.5	
404	8.875	315	0.75	
404	18	325	0.25	
404	24.5	325	1.5	
404	0.5	330	1.5	
405	24.5	20	1	
405	56.5	20	1.5x1	
405	2.25	50	1.25	
405	16.25	70	0.5	
405	52	70	0.5	
405	77.5	70	1.25	
405	72	80	1.25	
405	63	110	1.25	
405	10.5	120	0.25	
405	21	130	0.5	
405	25.5	130	1	
405	33	130	1	
405	37.5	170	2x1.5	
405	54	170	1	
405	17.75	180	0.25	
405	2.75	200	2	
405	70.25	200	1.5	
405	13.75	220	0.25	
405	35.25	240	1.75	
405	57.5	240	0.5	
405	1	280	1.25	
405	76.5	280	1.5	
405	11	310	0.5	
405	47.5	310	0.25	
405	59	310	0.75	
405	21	330	0.75	
405	37	350	1.5	
405	62.5	350	0.75	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
410	70.625	0	1.25	
410	8.5	5	0.25	
410	56.25	15	0.25	
410	28	20	1	
410	15.75	25	0.25	
410	18.25	30	0.25	
410	66.25	30	0.75	
410	7	40	0.25	
410	59.5	40	0.25	
410	TOP	40	1	
410	37.75	45	1.75	
410	0	50	1.25	
410	10	60	0.25	
410	24	60	0.25	
410	59.75	80	0.25	
410	21.875	85	1.25	
410	40.75	95	1.5	
410	14.625	100	0.25	
410	76.5	100	1.5	
410	31.75	110	0.5	
410	51.75	120	0.25	
410	62	120	0.25	
410	65.5	125	0.25	
410	36.125	130	0.25	
410	71.25	130	0.5	
410	15.25	135	0.25	
410	21	150	0.375	
410	1.5	155	1	
410	59.25	160	0.25	
410	40	165	1.5	
410	56.375	170	0.25	
410	7.875	180	0.25	
410	50.5	180	0.25	
410	77.25	185	2	
410	15.25	195	0.25	
410	34	200	1.25	
410	26.75	213	0.375	
410	17.375	215	0.25	
410	61.375	215	0.375	
410	68.375	220	0.75	
410	24	235	0.5	
410	40.25	235	2.25	
410	1	240	1.5	
410	54.75	255	0.25	
410	20.75	265	0.375	
410	38.875	275	2	
410	52.25	280	0.25	
410	76.75	280	2.25	
410	61.125	290	0.25	
410	32.875	300	1.25	
410	2.875	305	2	
410	27.75	305	0.5	
410	18.75	310	0.375	
410	13.75	315	.5x.25	
410	75.375	330	1.5	
410	59.25	340	0.5	
410	41	345	2	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
414	2	0	1.5	
414	54	10	0.25	
414	56.5	20	0.5	
414	39.5	80	1.5	
414	28	110	0.75	
414	64.25	120	0.5	
414	6.25	130	0.5	
414	45.5	160	0.25	
414	2.5	170	1	
414	41	180	1	
414	55.25	180	0.5	
414	66.5	180	0.5	
414	18.5	200	0.25	
414	56	210	0.25	
414	26	230	0.5	
414	29.5	260	0.5	
414	60.75	270	0.25	
414	66.5	270	0.5	
414	54	280	0.25	2 (.375") knots
414	19.75	290	0.5	
414	48	340	0.25	
414	66	350	0.25	
415	6.125	15	0.25	
415	60	15	1.5	
415	53.75	35	0.75	
415	14.75	40	1	
415	38.75	45	0.25	
415	3	55	0.5	
415	48.25	55	0.5	
415	46	65	0.25	
415	71.375	105	0.25	
415	39	110	0.25	
415	13.5	115	0.625	
415	53	120	0.75	
415	3.875	125	0.375	
415	60	125	2	
415	75.75	140	0.75	
415	20	155	1.5	
415	4.25	160	1.5	
415	15	175	0.75	
415	40.625	175	0.375	
415	18.75	200	1.25	
415	18.875	200	1.25	
415	45.625	205	0.375	
415	54	210	1.25	
415	57.5	220	1.5	
415	60.75	220	2.5x1.5	
415	5.5	225	0.75	
415	19.25	270	1.25	
415	31.75	270	0.25	
415	40.875	270	0.5	
415	0.5	310	0.25	
415	11.75	310	1	
415	71.75	315	0.25	
415	20	320	2	
415	27.25	340	0.25	
415	41.125	340	0.375	
415	44.5	350	1	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
417	34.5	0	0.875	
417	41.625	10	1	
417	77	10	1	
417	57.375	30	0.25	
417	0	35	1	
417	4	35	1.5	
417	43.375	75	1.125	
417	65.875	90	0.75	
417	19.5	100	0.25	
417	73	100	1.5	
417	2.25	105	1	
417	27.125	130	0.375	
417	76	135	1.5	
417	36	140	1	
417	38.5	170	1	
417	3.5	195	1.5	
417	18.25	195	0.125	
417	43.25	195	1.25	
417	62.375	210	0.25	
417	67.875	220	1.25	
417	74.75	230	1.5	
417	20.75	235	0.25	
417	27.75	270	0.75	
417	55.5	270	0.5	
417	44.75	280	0.25	
417	4.25	295	1.25	
417	0	305	2	
417	40	310	1.375	
417	56	310	0.75	
417	26.25	315	0.25	
417	19.25	320	0.25	
417	74.25	325	1	
417	63.5	335	0.25	
417	27.75	350	0.75	
418	TOP	5	1.25	
418	11.125	55	0.25	
418	46.75	60	0.5	
418	75.5	60	0.75	
418	22	75	1.25	
418	51.375	85	0.75	
418	78.625	95	0.75	
418	22.25	125	0.5	
418	45.375	130	0.375	
418	0-67"	150	Split	
418	48.625	180	1	
418	76.75	180	1.75	
418	24.75	200	1.5	
418	50.125	220	2	
418	21.25	225	0.5	
418	TOP	250	2	
418	45.75	255	1.25	
418	40.875	270	0.25	
418	7.75	280	0.25	
418	13.625	285	0.25	
418	75.25	285	1.5	
418	46.75	310	1.25	
418	22.25	315	1.75	
418	49.25	330	1	
418	70.5	340	0.25	
418	40.25	345	0.25	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
419	45.375	40	1	
419	12.25	45	1	
419	3	50	0.375	
419	21.5	70	1.125	
419	47.375	125	0.5	
419	22.875	135	1	
419	54.5	140	0.125	
419	11.75	145	0.75	
419	17.5	180	1	
419	68.875	180	0.25	
419	32.25	200	0.5	
419	22.375	230	1.25	
419	44.25	240	1.5	
419	61.875	240	0.5	
419	82.75	245	1.25	
419	2.25	265	1	
419	4.875	265	0.125	
419	68.5	270	0.375	
419	33.5	305	0.375	
419	18	330	0.75	
419	45.875	330	0.75	
419	TOP	330	0.75	
419	54.125	345	1.125	
419	23.625	350	1.25	
419	38.5	355	0.625	
421	53	0	0.375	
421	32.375	5	0.625	
421	8.125	10	0.75	
421	69.375	40	0.375	
421	18.625	45	0.75	
421	45.625	55	1	
421	13.125	65	0.25	
421	48.5	70	1	
421	0	80	1	
421	28.5	80	0.625	
421	5.375	90	0.75	
421	TOP	95	0.75	
421	16.5	115	0.625	
421	54.5	130	0.5	
421	70	140	0.75	
421	32.75	145	0.5	
421	66.375	145	0.25	
421	57.5	165	0.5	
421	26.375	170	0.25	
421	46.375	180	0.75	
421	8.5	205	0.75	
421	40	205	0.25	
421	0.5	225	0.5	
421	19.5	225	0.75	
421	32.75	255	0.75	
421	8.75	260	0.625	
421	16.5	260	0.375	
421	19.375	270	0.25	
421	54.75	270	0.25	
421	58.75	270	0.75	
421	66.375	285	0.25	
421	69.75	285	0.75	
421	41.5	290	0.25	
421	4.25	295	0.25	
421	46.125	295	0.75	
421	77.125	305	0.25	
421	0	325	0.75	
421	23.5	330	0.25	
421	41.125	345	0.375	
421	69.375	350	0.875	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
422	56.5	5	0.5	
422	25	10	0.625	
422	TOP	30	0.5	
422	42.5	80	0.25	
422	28.875	95	0.25	
422	44.375	120	0.375	
422	30.125	155	0.375	
422	57.5	185	0.375	
422	6.75	190	0.25	
422	4	250	0.25	
422	9	260	0.25	
422	44.375	260	0.375	
422	29	285	0.375	
422	10	305	0.25	
422	58.625	320	0.625	
422	29.875	340	0.625	
422	43.5	350	0.5	
425	58.625	0	0.5	
425	1.75	5	0.5	
425	41	5	0.5	
425	19	20	0.5	
425	32.625	25	0.375	
425	61.25	30	0.625	
425	51.25	45	0.25	
425	42.5	60	0.75	
425	71	60	0.5	
425	0.875	65	0.75	
425	57.125	80	0.75	
425	77.375	85	0.625	
425	20.375	100	0.625	
425	38.5	100	0.5	
425	61.5	125	0.5	
425	22.75	145	0.625	
425	2	155	0.5	
425	58.875	155	0.375	
425	14.75	160	0.375	
425	39.5	165	0.375	
425	52	185	0.25	
425	21.25	205	0.5	
425	59.75	215	0.375	
425	42.5	225	.625x.25	
425	40.625	275	0.25	
425	60.8	280	0.25	
425	21.25	325	0.5	
425	54.5	330	0.25	
425	70.875	350	0.125	
425	37.25	355	0.25	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
426	28	0	0.125	
426	17.25	30	0.5	
426	42.75	30	0.5	
426	77	30	0.5	
426	20.25	40	0.5	
426	75	40	0.5	
426	5.5	80	0.25	
426	12	80	0.125	
426	63	80	0.25	
426	41.5	110	0.75	
426	14.25	140	0.5	
426	57.5	140	0.125	
426	75.5	140	0.75	
426	31.5	150	0.25	
426	66.5	150	0.5	
426	20.25	180	0.75	
426	13	190	0.25	
426	35.75	190	0.5	
426	7.5	200	0.25	
426	43.25	230	0.75	
426	19	240	0.5	
426	31.5	260	0.25	
426	75	260	0.5	
426	62.5	280	0.25	
426	19.75	290	0.5	
426	8	310	0.125	
426	39.75	340	0.5	
426	71	350	0.25	
429	5.5	170	0.5	
431	22.75	0	0.625	
431	37.125	20	0.375	
431	4.75	25	0.5	
431	32.25	45	0.375	
431	74.75	130	0.375	
431	30.75	135	0.25	
431	37	135	0.5	
431	63.25	150	0.375	
431	26	155	0.25	
431	43.625	155	0.75	
431	68.375	170	0.5	
431	10.25	180	1.5	
431	58.875	180	1	
431	5	185	0.375	
431	38.125	190	1	
431	54.375	195	1.25	
431	76	205	1	
431	32	215	1.5	
431	15.25	225	1	
431	27.5	225	0.75	
431	17.875	230	0.375	
431	63.5	240	0.625	
431	25.375	245	1.25	
431	54.875	245	0.75	
431	4.5	260	1.25	
431	35.5	260	0.25	
431	69.5	265	0.625	
431	44.375	275	0.375	
431	37.875	295	0.375	
431	58.5	295	0.375	
431	10	305	0.75	
431	31	305	0.25	
431	68.75	325	0.25	
431	74.75	340	0.25	
431	0.5	345	0.25	
431	62.875	350	0.25	
431	41.75	355	0.25	

Post Number	Knot Location		Knot Diameter (in.)	Comments:
	From Bottom (in.)	Front CCW (Deg.)		
432	9	10	0.5	
432	31	10	.375x.75	
432	61.125	20	0.25	
432	4.375	25	1.5	
432	46.875	35	1	
432	41.875	40	1.5	
432	66.25	40	0.25	
432	75	40	0.5	
432	53.875	45	0.25	
432	54.125	80	0.25	
432	44.75	90	0.5	
432	69.75	90	0.5	
432	12.75	100	0.75	
432	15.25	125	1	
432	72.75	125	0.5	
432	33	145	0.375	
432	35.75	150	0.375	
432	47.25	155	1	
432	13.375	160	0.75	
432	27.75	165	0.25	
432	10.5	170	0.5	
432	75.375	170	1.25	
432	4.875	225	0.75	
432	3.375	245	0.5	
432	75.625	270	1.7500	
432	70	295	1.25	
432	71.625	320	1.5	
432	14.875	325	2	
432	21.125	335	0.25	
432	63	335	0.25	
432	72.875	350	1	
433	1	10	0.125	
433	55.5	15	0.25	
433	36.25	20	0.375	
433	12.625	30	0.5	
433	69.5	35	1.5	
433	20.5	40	1	
433	44.75	40	1.5	
433	16.125	85	0.25	
433	43.875	85	0.75	
433	19.375	100	0.5	
433	71.375	100	0.75	
433	62.5	105	0.2500	
433	70	115	0.5	
433	20.625	175	0.375	
433	44	175	0.5	
433	14.125	200	0.25	
433	17.25	235	0.25	
433	70	235	0.625	
433	19.25	270	0.625	
433	43.25	270	0.25	
433	45	300	0.875	
433	68.375	300	0.25	
433	29	310	0.125	
433	71.625	320	1	
433	19.75	330	1	
433	41.75	340	1.5	
433	14.375	350	0.625	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
434	5.25	0	0.25	
434	48	20	0.5	
434	39	30	0.5	
434	28.5	40	1	
434	62	40	0.75	
434	16	50	0.75	
434	5.5	60	1.5	
434	35.5	100	0.5	
434	47.5	110	0.75	
434	63	110	1	
434	12	120	0.25	
434	17	130	0.75	
434	38	130	0.75	
434	5	140	1	
434	27	150	0.5	
434	15.75	180	0.25	
434	28.75	180	0.5	
434	39	180	0.5	
435	0.5	0	0.75	
435	67	0	0.75	
435	41.25	10	0.25	
435	25	20	1	
435	60.25	30	0.25	
435	14	40	0.25	
435	46.75	40	1.25	
435	38.5	60	0.25	
435	43.5	60	1	
435	23	90	0.75	
435	66.5	100	1.25	
435	25.25	120	0.75	
435	34.25	120	0.25	
435	59.25	120	0.25	
435	38	130	0.25	
435	45.5	130	0.5	
435	67	140	0.5	
435	0.5	150	0.5	
435	56.25	160	0.25	
435	43.25	170	0.5	
435	22.5	180	0.5	
435	62	180	0.25	
435	12.75	190	0.25	
435	47	210	0.5	
435	24.5	220	0.5	
435	68	240	0.5	
435	47	260	0.75	
435	25.5	290	0.5	
435	65.25	300	0.5	
435	67.25	300	0.5	
435	23	330	0.5	
435	46	330	0.75	

Table A-8. Douglas Fir – Round 2 - Length and Circumference Measurements

	Length (in.)	Avg. Length (in.)	Circumference (in.)		
			Location	Critical Zone	Critical Zone
Douglas Fir	78.125	78.125	Top	19.500	19.917
	78.125		Mid-length	19.750	
	78.125		Bottom	20.500	
	78.188	78.188	Top	22.375	22.542
	78.188		Mid-length	22.250	
	78.188		Bottom	23.000	
	78.125	78.167	Top	21.500	22.083
	78.250		Mid-length	22.000	
	78.125		Bottom	22.750	
	78.125	78.125	Top	20.750	21.375
	78.125		Mid-length	21.375	
	78.125		Bottom	22.000	
	78.125	78.167	Top	21.250	22.292
	78.250		Mid-length	22.625	
	78.125		Bottom	23.000	
	78.125	78.125	Top	20.750	21.625
	78.125		Mid-length	22.000	
	78.125		Bottom	22.125	
	78.125	78.146	Top	21.125	21.792
	78.125		Mid-length	21.750	
	78.188		Bottom	22.500	
	78.125	78.083	Top	20.125	20.750
	78.125		Mid-length	21.000	
	78.000		Bottom	21.125	
	78.125	78.125	Top	22.375	23.083
	78.125		Mid-length	23.000	
	78.125		Bottom	23.875	
	78.125	78.167	Top	21.625	22.208
	78.125		Mid-length	22.125	
	78.250		Bottom	22.875	
	78.125	78.146	Top	21.750	21.917
	78.125		Mid-length	21.875	
	78.188		Bottom	22.125	
	78.125	78.125	Top	20.875	21.458
	78.125		Mid-length	21.625	
	78.125		Bottom	21.875	
	78.125	78.167	Top	20.875	21.083
	78.250		Mid-length	21.000	
	78.125		Bottom	21.375	
	78.125	78.125	Top	21.875	22.042
	78.125		Mid-length	22.000	
	78.125		Bottom	22.250	
	78.125	78.125	Top	22.625	22.792
	78.125		Mid-length	22.500	
	78.125		Bottom	23.250	

Table A-9. Douglas Fir Round 2 Pre-test Documentation

	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume (in.^{3})	Density (lb/in.^{3})	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Douglas Fir	401	63	78.125	19.917	19.125	20.500	2458	0.0256	65	58	71	3.67
	403	55	78.188	22.542	21.250	24.000	3165	0.0174	67	65	63	4.33
	404	78	78.167	22.083	20.000	22.500	2971	0.0263	53	49	39	4.33
	405	63	78.125	21.375	20.500	22.625	2852	0.0221	65	67	71	4.00
	410	59	78.167	22.292	21.750	23.125	3097	0.0191	66	65	69	3.67
	414	52	78.125	21.625	20.750	22.250	2894	0.0180	47	56	51	4.00
	415	59	78.146	21.792	20.750	22.625	2943	0.0200	74	71	74	3.67
	417	58	78.083	20.750	20.875	23.125	2764	0.0210	60	63	61	3.67
	418	65	78.125	23.083	22.250	24.125	3319	0.0196	22	30	29	5.67
	419	65	78.167	22.208	21.500	22.875	3062	0.0212	32	48	48	5.67
	421	68	78.146	21.917	21.625	22.375	2988	0.0228	60	66	63	12.33
	422	71	78.125	21.458	20.500	20.750	2799	0.0254	21	21	22	7.67
	425	62	78.167	21.083	20.500	21.250	2745	0.0226	36	32	26	9.33
	426	63	78.125	22.042	22.000	22.625	3036	0.0207	67	65	70	8.33
	429	69	78.125	22.792	22.625	23.250	3238	0.0213	59	39	70	5.67

Table A-10. Knot Locations for Ponderosa Pine Posts Cantilever Testing Round 2

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
502	3.125	0	2	
502	2.875	20	0.25	
502	47.5	30	0.255	
502	62	30	1	
502	60.375	55	0.25	
502	33.375	70	2	
502	49.875	115	1.75	
502	63.75	115	2x1.75	
502	7	130	2x1.75	
502	22	130	2x1.25	
502	31.875	145	0.5	
502	5.5	155	0.5	
502	12	160	0.5	
502	61.5	175	0.5	
502	50.25	205	2	
502	32.625	230	1.125	
502	12.25	245	0.5	
502	20.5	245	1.75	
502	62.625	250	1.5	
502	48.375	265	0.375	
502	33	295	1.5	
502	12.5	315	1	
502	63.25	325	1	
502	49.5	330	1.25	
502	19.625	350	0.5	
502	31.875	355	1.25	
505	10.25	0	2	
505	51.5	15	3x2	
505	65.75	30	2	
505	48.125	80	0.25	
505	38.5	90	3	
505	8.125	120	5x2	
505	65	120	1.5	
505	6.25	150	0.25	
505	23.75	160	2.75x1.5	
505	51	160	3x2.25	
505	40	185	2x.75	
505	67.25	190	4x2.5	
505	0	200	1.5	
505	15.75	200	0.5	
505	64.75	230	0.75	
505	50	250	2	
505	67.125	290	2.5x2	
505	13.625	330	0.25	
505	6.75	345	0.25	

Post Number	Knot Location From Bottom (in.)	Front CCW (Deg.)	Knot Diameter (in.)	Comments:
506	5.5	5	0.75	
506	18.25	15	0.25	
506	38.75	15	1.5	
506	52	50	1.25x1	
506	16	60	2.75x2	
506	3	65	4x2.5	
506	29.75	70	2.25	
506	70.125	105	2.5	
506	54.75	115	2.25	
506	29	170	3x2	
506	39.5	170	1	
506	72.625	170	0.5	
506	52.5	180	1.25	
506	5.25	190	1.25	
506	17.875	205	0.5	
506	39	225	1.75	
506	4	295	2	
506	15.625	300	2x1.5	
506	52.5	305	.75x.25	
506	29	310	1.75	
506	69	310	2x1	
508	54.5	0	2	
508	23.875	20	0.25	
508	15.25	40	1.5	
508	38.875	40	0.25	
508	26.5	90	3x1.875	
508	62.25	110	0.25	
508	15.5	115	2.5	
508	71	125	0.75	
508	41.5	130	3.25x2	
508	0	145	2	
508	51.5	180	0.25	
508	26.75	190	3x2	
508	14.25	200	1	
508	72.625	220	0.625	
508	24.125	255	0.125	
508	15.75	260	2.25	
508	40.75	270	2.5	
508	54.5	280	2.5x1.75	
508	13.375	330	0.375	
508	25.75	330	2	
508	40.375	345	1.75	
508	64	350	0.75	
508	71.5	350	0.5	
510	5	15	2	
510	24.25	25	1.25	
510	30	45	1.75	
510	61.375	45	1.75	
510	9.25	65	1.5	
510	5	120	2	
510	62	120	3x2	
510	18.5	125	1.125	
510	24.375	135	1.25	
510	35	150	0.5	
510	27.625	160	0.25	
510	19	205	1.5	
510	9.625	210	1.5	
510	36.75	250	1.25x1	
510	20.375	275	0.875	
510	7.375	285	0.25	
510	44.25	320	1.125	
510	19	330	1.5	
510	61.25	330	1.5	

Post Number	Knot Location From Bottom (in.)	Front CCW (Deg.)	Knot Diameter (in.)	Comments:
515	52.75	20	3.25x1.75	
515	25.5	25	1.5	
515	0	30	1.5	
515	5.75	35	1.25	
515	34.875	60	1.5	
515	13.25	80	2	
515	6.5	285	0.75	
515	35.125	300	2	
515	20.5	325	0.75	
515	11.875	350	0.25	
515	33.625	350	0.625	
515	32.125	360	0.125	
515	35.5	360	0.25	
516	76	30	1.25	FROM TOP
516	55	80	0.75	FROM TOP
516	65.5	80	0.25	FROM TOP
516	74.25	100	0.5	FROM TOP
516	55	130	0.75	FROM TOP
516	76	150	1.5	FROM TOP
516	67	160	1.5	FROM TOP
516	56	210	1.75	FROM TOP
516	66	220	0.25	FROM TOP
516	68	270	1	FROM TOP
516	55.5	350	1	FROM TOP
516	67	360	1.25	FROM TOP
517	31.75	5	1.5	
517	49.5	20	1.5	
517	62	40	1.75	
517	23	50	1.25	
517	74.75	50	1.125	
517	39.75	70	1	
517	32.125	80	1.75	
517	9.25	95	1.75	
517	31.125	150	0.375	
517	48	150	0.75	
517	74.25	150	1.5	
517	23.625	170	1.75	
517	60.875	170	1.25	
517	71.625	200	0.25	
517	72.25	200	1.75	
517	6.125	210	0.25	
517	48.875	230	1.375	
517	32.5	245	1.5	
517	22.375	280	0.375	
517	71.875	280	0.125	
517	39.5	300	1	
518	13.5	25	2	
518	11.5	65	0.5	
518	60.75	110	0.5	
518	64.125	150	1.75x1.25	
518	48.375	155	2x1	
518	30.25	170	0.75	
518	33	215	2.5x1.5	
518	0	245	1	
518	22.25	275	2x1.5	
518	31.25	315	0.125	
518	50.875	320	4x2.5	
518	8.25	325	0.25	
518	66.25	340	4x2.25	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
519	49.875	0	0.5	
519	68.625	10	1.25	
519	57.625	20	1.5	
519	4.125	55	0.75	
519	57.375	65	0.875	
519	65.625	80	0.25	
519	29.375	110	1.5	
519	51.625	120	1	
519	0	125	1	
519	67.25	190	1	
519	31.125	200	2x1	
519	58	205	1.5	
519	29.75	335	1.5	
521	24.5	170	0.75	
521	8.5	190	0.75	
521	53.5	200	0.25	
521	46	230	1	
521	77.5	300	0.75	
526	NO KNOTS			
527	5.875	5	0.625	
527	13.625	10	0.25	
527	63.5	20	0.75	
527	24.875	50	0.375	
527	10.625	160	0.625	
527	31.375	170	0.75	
527	5.375	180	1	
527	20.25	230	1.25	
527	16.5	320	0.75	
528	58.75	140	0.25	
528	70.375	190	0.5	
528	60.25	210	0.5	
528	76.375	240	0.5	
530	52.875	230	0.25	
530	54.875	245	0.375	
530	61	275	0.25	
530	52.625	300	1.25x1	
575	64	0	1.5	
575	22.25	10	2.5x1	
575	53.5	20	3x1.875	
575	70.125	20	1.75	
575	42.5	50	1.25x1	
575	17.25	90	1.25x.25	
575	33.875	130	1.5	
575	53.125	130	0.75	
575	51.375	135	0.75	
575	71.375	135	2x1.75	
575	58	140	1.25	
575	18.5	155	0.75	
575	5	185	2	
575	7.75	190	0.75	
575	71.5	190	1	
575	74.75	190	0.125	
575	25.625	205	1	
575	13.375	210	1.75	
575	34.875	210	1.75	
575	22	225	2x1.5	
575	58.875	225	1	
575	62.875	270	2	
575	35	275	0.75	
575	71.75	275	2.5x1.5	
575	19	285	0.5	
575	65.5-69.25	285	1" wide	ROTTED
575	44.375	295	0.5	
575	8.25	305	1	
575	50.25	310	0.5	
575	27.25	330	1	

Post Number	Knot Location From Bottom (in.)	Front CCW (Deg.)	Knot Diameter (in.)	Comments:
576	9.625	5	2	
576	36.375	5	0.25	
576	71.875	35	2x1	Rotted
576	37.875	90	1.625x1	
576	69.25	100	1	
576	23.375	145	0.375	
576	12.25	165	0.25	
576	71.125	170	1	
576	35-55	180		Rotted Knot 2" Wide
576	26.125	210	0.875	
576	11.25	220	0.25	
576	57.125	255	0.875	
576	23.25	275	0.25	
576	12.5	290	0.375	
576	54.125	325	1.25	
576	35.5	330	0.25	
576	1.75	350	0.25	
577	61	50	0.5	
577	46.25	80	0.25	
577	51.5	110	0.25	
577	72.25	120	0.5	
577	61	140	0.5	
577	69.5	150	0.125	
577	43.25	180	0.25	
577	13.75	300	0.25	
577	61	340	0.5	
578	4.25	30	0.25	
578	68.5	65	1.25	
578	74.5	90	0.25	
578	29.25	100	1.25x1	
578	5.875	130	0.375	
578	39	135	1.75x1	
578	10.875	140	0.375	
578	44.375	180	0.5	
578	19.25	185	0.625	
578	52.625	210	0.25	
578	38	260	1.125	
578	49	265	0.25	
578	72.375	265	0.25	
578	53	275	5x1.5	
578	51.375	305	0.75	
578	56.875	320	0.375	
578	0	350	0.25	
578	57.25	350	0.75	
578	11.875	355	2x1.5	

Post Number	Knot Location From Bottom (in.)	Knot Location Front CCW (Deg.)	Knot Diameter (in.)	Comments:
579	72	20	0.75	
579	27	45	2x1	
579	11	70	1.5x1	
579	33.25	80	0.5	
579	48.25	90	2	
579	27	120	1.75x1	
579	45.25	130	0.25	
579	60.5	140	2x1.5	
579	10.5	150	1	
579	25	170	0.75	
579	9.25	190	0.5	
579	47.25	190	0.5	
579	61	210	1.75	
579	33.25	220	0.375	
579	36	280	1.5	
579	57.25	280	0.25	
579	73.75	300	1.5	
579	8.75	320	0.5	
579	47	325	1.5	
580	2.25	0	0.75	
580	11.5	5	1	
580	TOP	35	0.75	
580	36.25	50	1.5x1	
580	23.5	80	0.375	
580	67	120	0.75	
580	22.125	145	0.5	
580	0.75	150	1.25	
580	11.25	150	0.75	
580	37	150	2x1.25	
580	62.5	190	0.375	
580	67.5	210	1.5	
580	22.5	220	0.75	
580	52	230	2.5x1.25	
580	22	270	1.25	ROT ON POST 290-220 3.5" to 19.5"
580	1	280	1	
580	37	280	1	
580	TOP	290	0.75	
580	54.25	310	0.875	
580	38.375	330	0.375	
580	66.25	335	0.75	
580	22	350	0.75	
580	38	355	0.5	
581	36	0	1	
581	6	10	1	
581	44	15	1.5x1	
581	25.75	50	1	
581	8.75	90	0.5	
581	4.25	100	0.25	
581	12.75	100	1	
581	56.5	110	0.875	
581	69.75	150	6x1.75	
581	19.5	160	0.875	
581	25.25	170	1	
581	58.25	180	1.5	
581	38.25	220	1.5	
581	5.625	230	0.75	
581	25	250	0.5	Through 31 in. 1.625 in. wide (large gouge)
581	20	270	1.5	
581	73	270	0.25	
581	12.5	310	0.75	
581	56.5	320	2	
581	59.5	330	2x1.5	
581	49.375	340	0.25	
581	9.25	700	1.125	

Post Number	Knot Location From Bottom (in.)	Front CCW (Deg.)	Knot Diameter (in.)	Comments:
582	27.625	25	0.75	
582	49.25	25	1.5x1	
582	37.75	55	0.25	
582	43.125	65	0.75	
582	41.75	80	1	
582	34.75	95	0.75	
582	38	100	0.25	
582	55.5	100	0.5	
582	31.25	125	0.75	
582	38.75	140	0.25	
582	39.75	145	2x1.25	
582	61.5	145	0.5	
582	27.625	155	0.75	
582	24.5	160	0.625	
582	73	165	0.25	
582	43.125	210	1.25	
582	19.5	220	0.5	
582	74.75	225	0.75	
582	70.75	230	1.75	
582	24.125	240	0.625	
582	35.125	245	0.5	
582	9	250	0.375	
582	67.75	260	1.25x.75	
582	74.75	280	0.5	
582	14.75	320	1.5	
582	58.25	320	0.75	
582	61.5	350	0.25	
582	18.625	360	0.75	
582	74.5	360	0.625	
583	11	0	0.5	
583	32.5	20	0.5	
583	50	30	0.5	
583	68	50	0.5	
583	7	60	0.75	
583	62.5	150	0.5	
583	69	160	1.25	
583	24.5	170	0.5	
583	32.75	180	1.25	
583	15	200	0.5	
583	11.25	220	0.5	gouge (2"x6")
583	62	220	0.5	
583	68	220	0.75	
583	20	230	0.5	
583	50	230	1.5	
583	43.5	250	1	
583	57	250	0.5	
583	7	270	1	
583	41	270	0.5	gouge (7.75" long x 1" wide)
583	27.25	310	1.25	
583	14.75	320	0.75	
583	18	330	0.25	
583	42.75	340	1	

Post Number	Knot Location From Bottom (in.)	Front CCW (Deg.)	Knot Diameter (in.)	Comments:
584	0-TOP	0	Split	NOT CONTINUOUS
584	58.375	50	0.375	
584	41	55	0.5	
584	42.25	170	.5x.25	
584	74.5	175	1x.75	
584	40-TOP	200	Split	
585	75.75	10	0.375	
585	33.625	20	0.5	
585	22	40	2	
585	9.625	50	1.125	
585	68.25	50	4x2.5	
585	45.625	70	0.5	
585	57.5	80	1.5	
585	23.125	100	0.125	
585	10.75	120	0.125	
585	44.75	145	1.75	
585	22.75	170	1.5	
585	10.125	180	1.625	
585	45.125	220	0.5	
585	45.875	230	0.125	
585	21	260	3.5x2.5	
585	10.875	280	0.5	
585	23.25	330	0.375	
585	77	330	2.5	
585	10.625	340	0.25	
585	68.25	350	0.5	

Table A-11. Ponderosa Pine - Round 2 - Length and Circumference Measurements

	Length (in.)	Avg. Length (in.)	Circumference (in.) Location	Critical Zone	Critical Zone
Ponderosa Pine	78.125	78.125	Top	22.375	22.208
	78.125		Mid-length	21.750	
	78.125		Bottom	22.500	
	78.125	78.042	Top	22.125	22.458
	78.000		Mid-length	22.500	
	78.000		Bottom	22.750	
	78.125	78.083	Top	22.000	22.208
	78.125		Mid-length	21.750	
	78.000		Bottom	22.875	
	78.000	78.000	Top	21.625	22.667
	78.000		Mid-length	22.375	
	78.000		Bottom	24.000	
	78.000	78.000	Top	20.625	20.083
	78.000		Mid-length	19.250	
	78.000		Bottom	20.375	
	78.000	78.042	Top	19.375	19.917
	78.125		Mid-length	19.750	
	78.000		Bottom	20.625	
	78.000	78.000	Top	21.000	20.833
	78.000		Mid-length	20.750	
	78.000		Bottom	20.750	
	77.875	77.958	Top	21.250	21.583
	78.000		Mid-length	22.000	
	78.000		Bottom	21.500	
	78.125	78.125	Top	21.500	21.208
	78.125		Mid-length	20.750	
	78.125		Bottom	21.375	
	78.125	78.167	Top	20.250	20.250
	78.125		Mid-length	20.250	
	78.250		Bottom	20.250	
	78.000	78.042	Top	23.250	23.833
	78.000		Mid-length	23.500	
	78.125		Bottom	24.750	
	78.125	78.125	Top	24.000	23.708
	78.125		Mid-length	23.125	
	78.125		Bottom	24.000	
	78.000	78.083	Top	22.250	22.375
	78.125		Mid-length	22.125	
	78.125		Bottom	22.750	
	78.125	78.125	Top	23.250	23.292
	78.125		Mid-length	23.500	
	78.125		Bottom	23.125	
	78.125	78.146	Top	22.875	23.083
	78.188		Mid-length	22.750	
	78.125		Bottom	23.625	

Table A-12. Ponderosa Pine Round 2 Pre-test Documentation

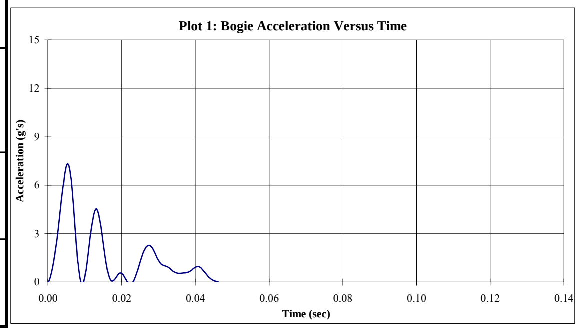
	Post Number	Weight (lb)	Avg. Length (in.)	Circumference (in.)			Volume (in.^{3})	Density (lb/in.^{3})	Moisture Content (%)			Ring Density (rings/in.)
				Critical Zone Average	Top	Bottom			21" From Top	21" From Bottom	Center	
Ponderosa Pine	502	58	78.125	22.208	22.625	22.875	3105	0.0187	15	17	17	5.67
	505	59	78.042	22.458	21.250	24.500	3167	0.0186	15	17	15	6.33
	506	48	78.083	22.208	22.750	25.125	3201	0.0150	17	15	17	4.67
	508	55	78.000	22.667	22.000	25.000	3263	0.0169	10	9	10	4.33
	510	53	78.000	20.083	20.750	21.625	2586	0.0205	14	13	12	3.33
	515	48	78.042	19.917	20.500	22.000	2557	0.0188	36	30	44	5.33
	516	47	78.000	20.833	22.000	21.750	2769	0.0170	17	16	17	7.00
	517	45	77.958	21.583	21.250	21.500	2875	0.0157	13	13	13	5.33
	518	57	78.125	21.208	21.750	22.250	2852	0.0200	30	31	27	6.67
	519	43	78.167	20.250	19.500	20.750	2537	0.0169	14	15	19	7.67
	521	66	78.042	23.833	24.000	24.500	3563	0.0185	14	14	15	15.00
	526	54	78.125	23.708	23.875	24.000	3511	0.0154	16	16	17	19.33
	527	56	78.083	22.375	22.250	23.750	3157	0.0177	18	16	22	13.33
	528	67	78.125	23.292	23.375	23.875	3393	0.0197	11	13	11	26.33
	530	73	78.146	23.083	23.625	24.000	3367	0.0217	33	43	31	15.00

Appendix B. Round 1 Cantilever Bogie Test Results

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	SY-1		
Test Date:	17-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	186.7 mm Dia. metric	7.44 in. Dia.	
Post Length:	196.0 cm	(497.7 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	8.4 m/s	(18.9 mph)	(27.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		



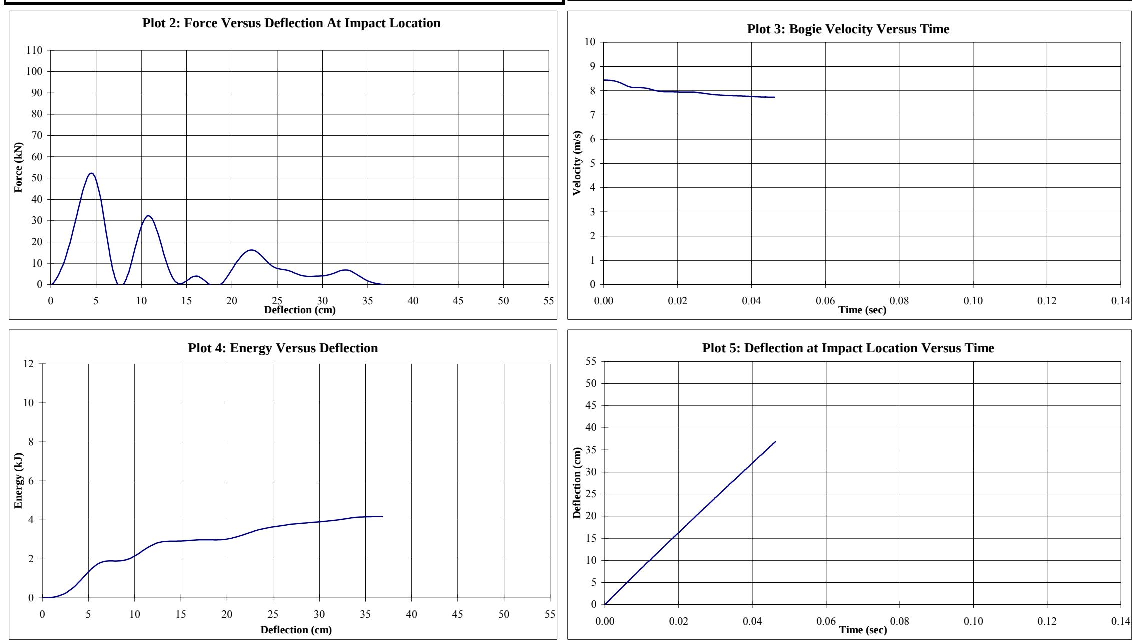
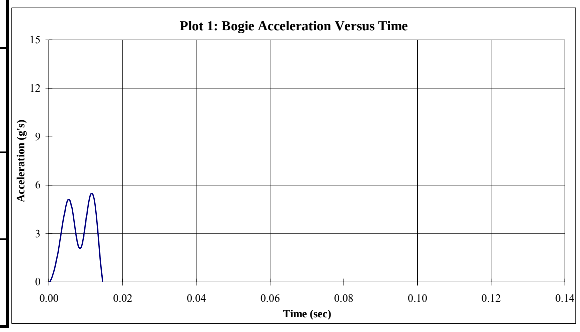


Figure 55. Results of Test No. SY-1

Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	SY-2		
Test Date:	17-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	186.7 mm Dia.	metric	7.10 in. Dia.
Post Length:	196.2 cm		(498.4 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		



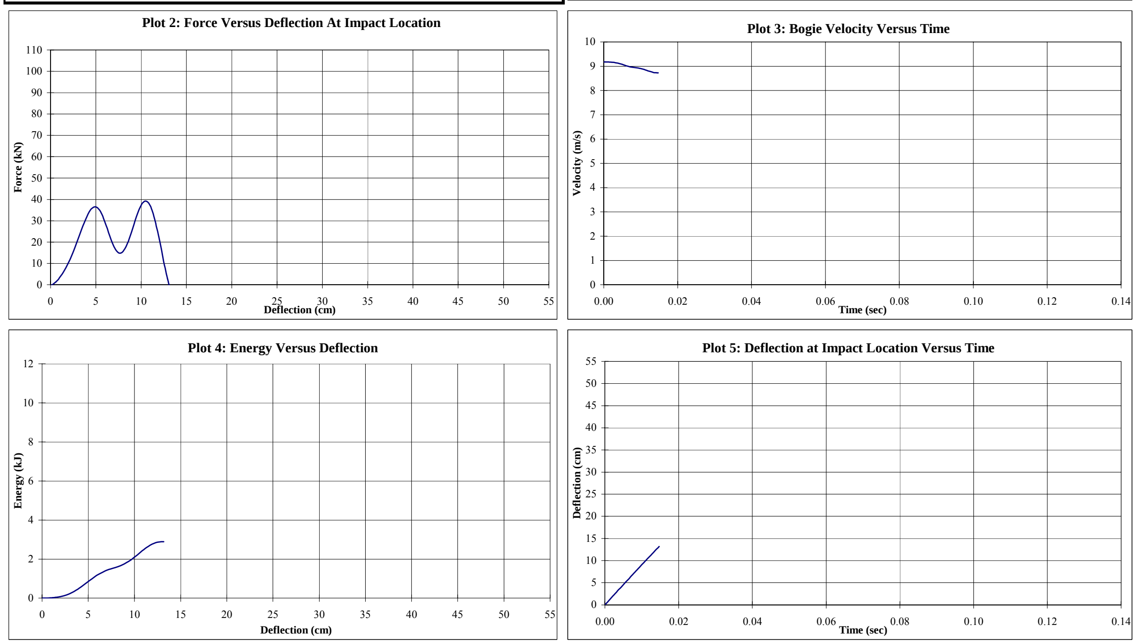
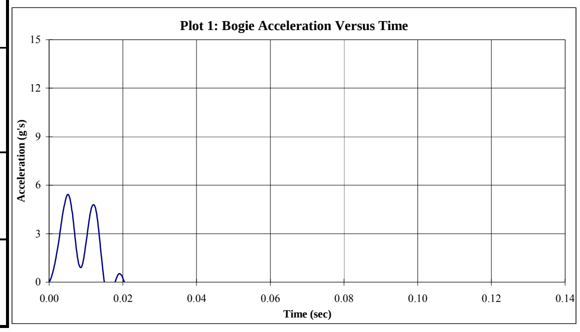
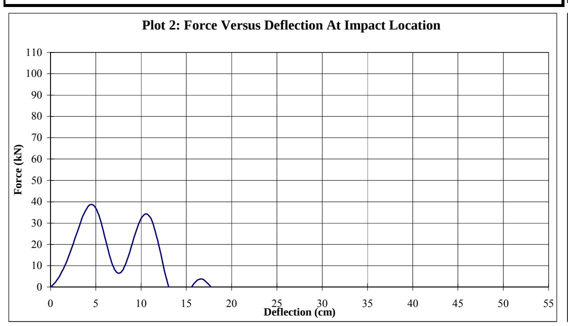


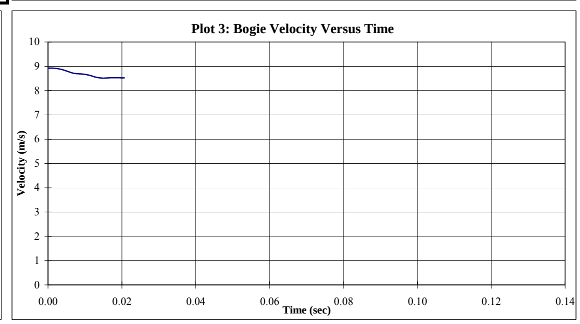
Figure 56. Results of Test No. SY-2

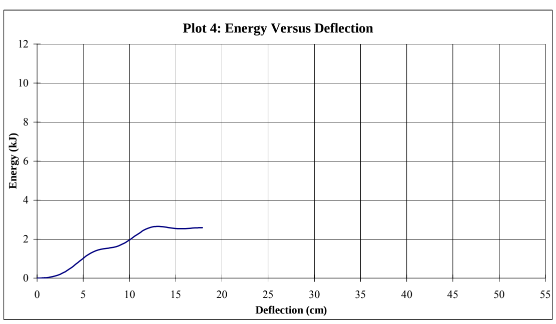
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	SY-3	
Test Date:	17-Nov-2004	
Failure Type:	0	
Post Properties		
Post Type:	Southern Yellow Pine - Round Wooden	
Post Size:	186.7 mm Dia. metric	7.40 in. Dia.
Post Length:	197.3 cm	(501.2 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	KNOTS	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	8.9 m/s	(20.0 mph) (29.3 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









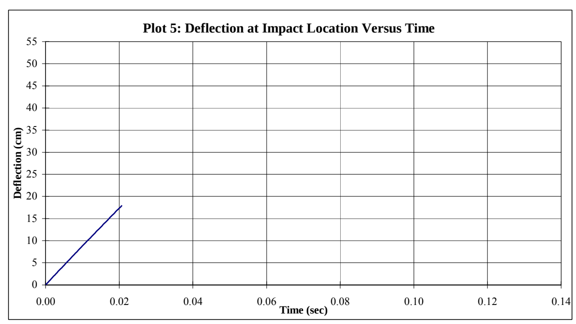
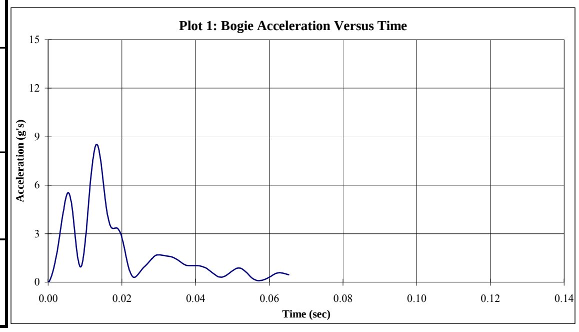
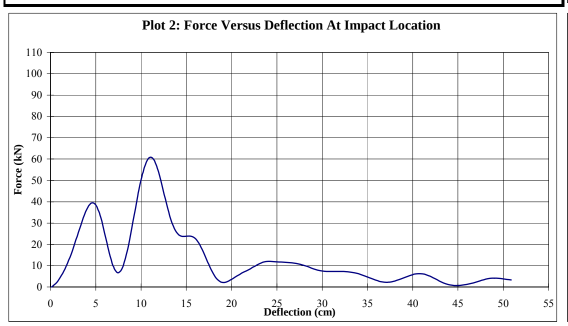


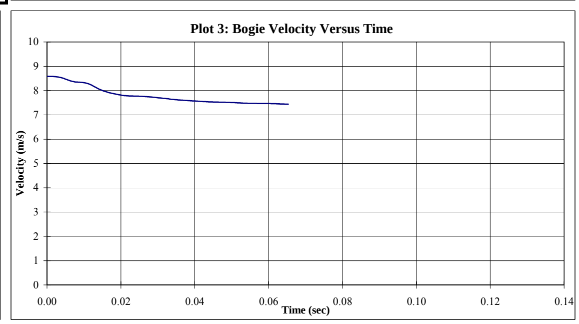
Figure 57. Results of Test No. SY-3

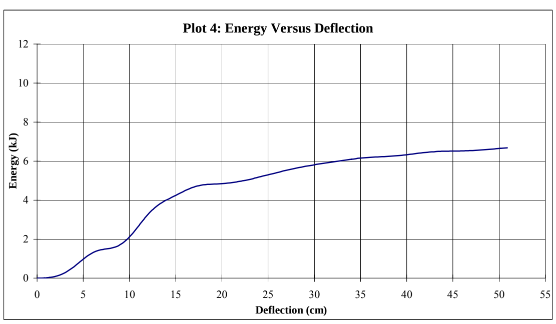
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	SY-4		
Test Date:	17-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	186.7 mm Dia. metric	7.25 in. Dia.	
Post Length:	196.8 cm	(499.9 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	KNOTS		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	8.6 m/s	(19.2 mph)	(28.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









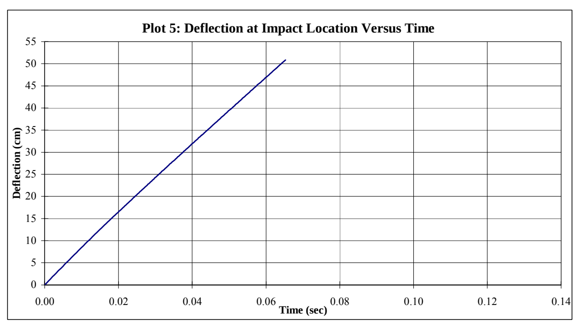
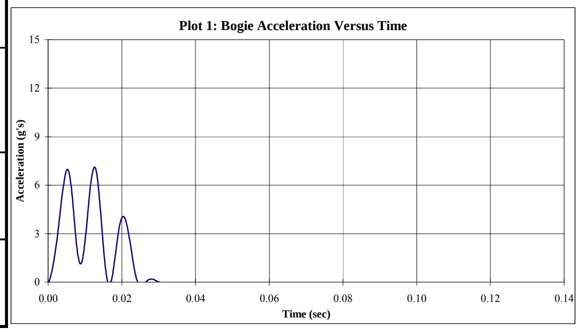


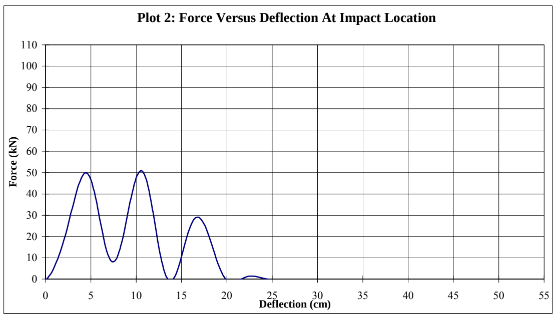
Figure 58. Results of Test No. SY-4

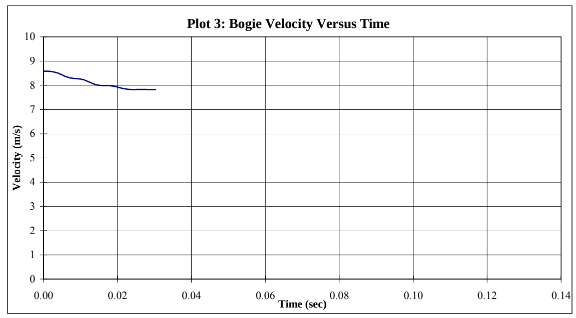
Midwest Roadside Safety Facility

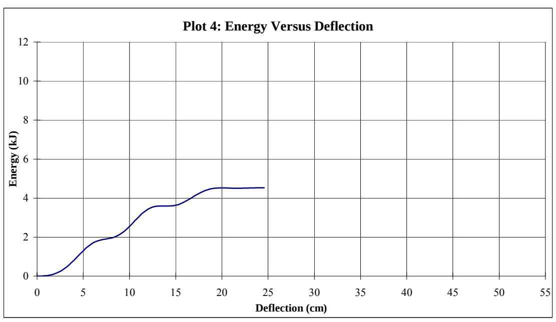
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	SY-5	
Test Date:	8-Dec-2004	
Failure Type:	0	
Post Properties		
Post Type:	Southern Yellow Pine - Round Wooden	
Post Size:	189.0 mm Dia. metric	7.44 in. Dia.
Post Length:	198.5 cm	(504.3 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	KNOTS	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	8.6 m/s	(19.2 mph) (28.2 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









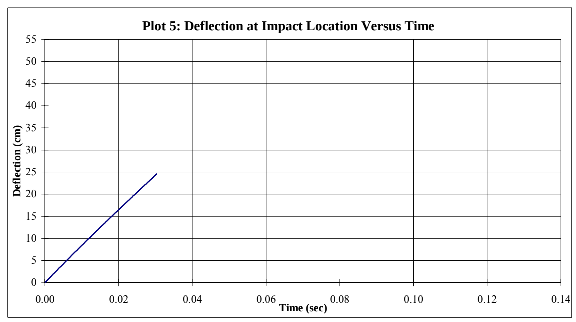
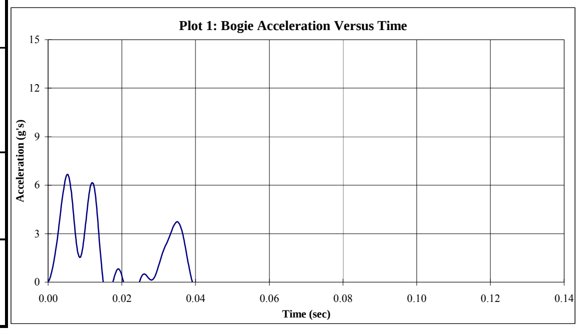


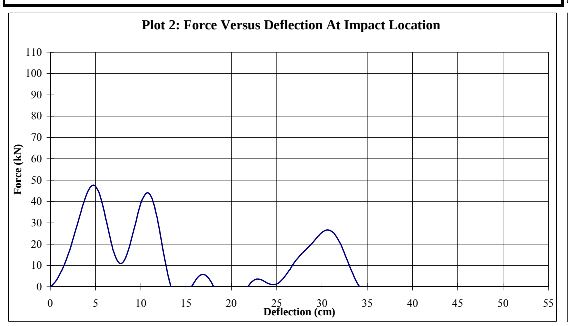
Figure 59. Results of Test No. SY-5

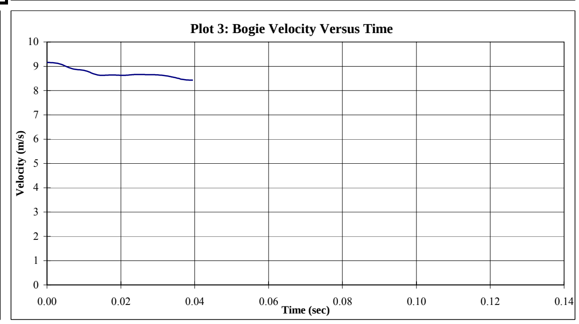
Midwest Roadside Safety Facility

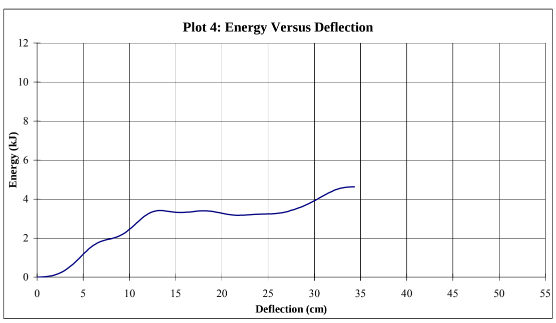
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	SY-6		
Test Date:	8-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	188.2 mm Dia. metric	7.41 in. Dia.	
Post Length:	198.6 cm	(504.4 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	BASELINE		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









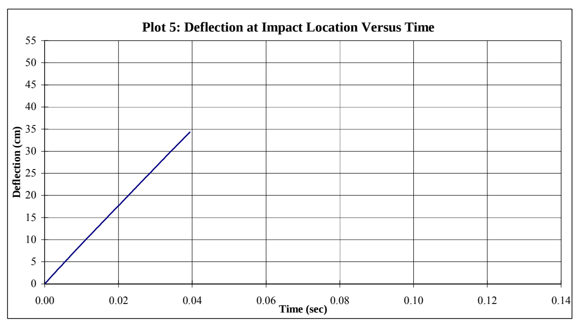
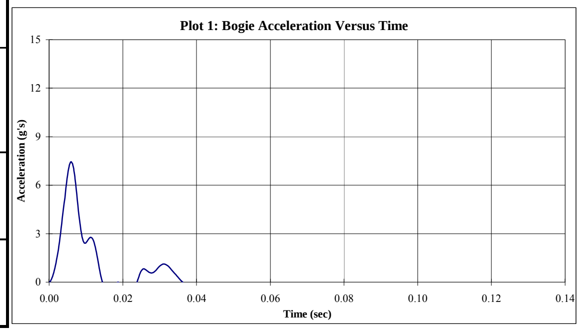
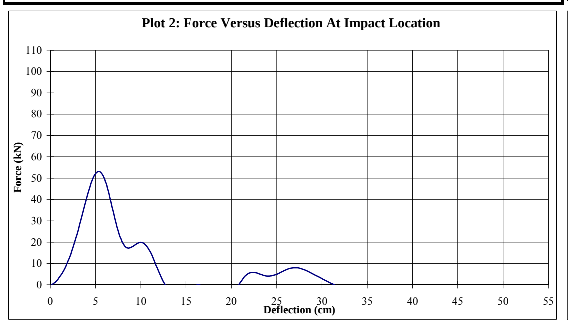


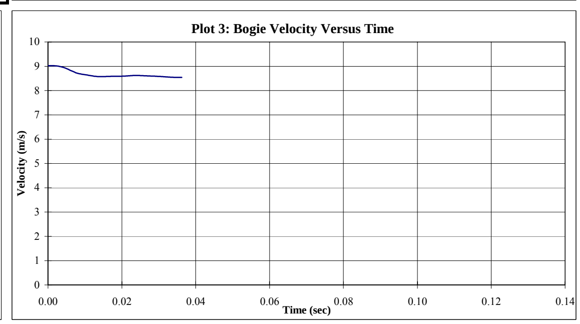
Figure 60. Results of Test No. SY-6

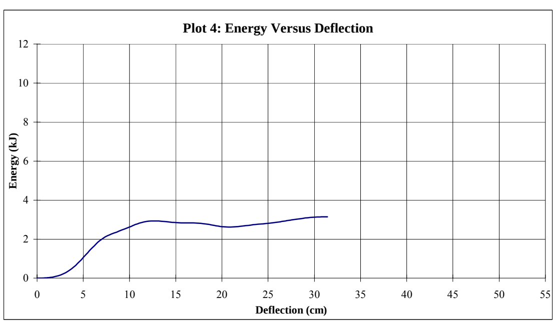
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	SY-7		
Test Date:	8-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	190.0 mm Dia.	metric	7.48 in. Dia.
Post Length:	195.4	cm	(496.3 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	BASELINE		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









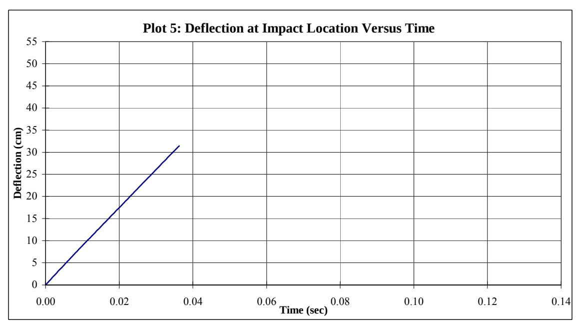
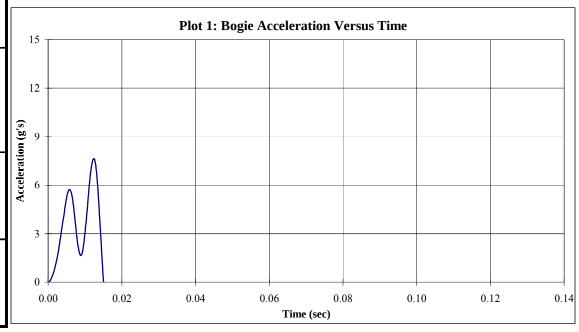


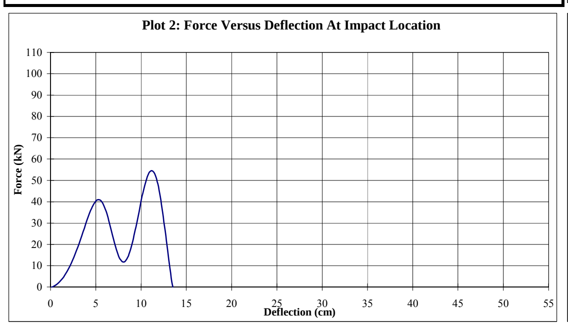
Figure 61. Results of Test No. SY-7

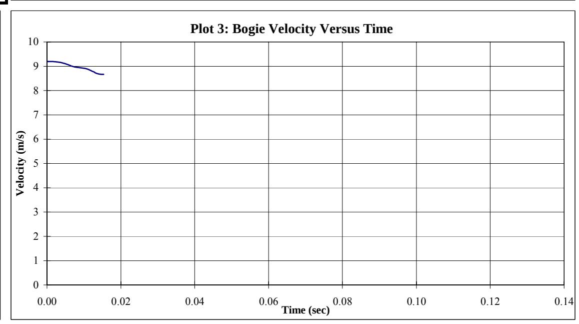
Midwest Roadside Safety Facility

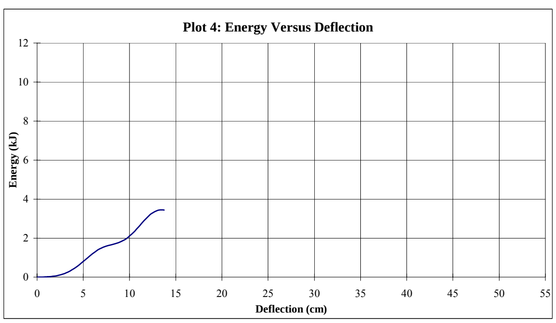
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	SY-8	
Test Date:	8-Dec-2004	
Failure Type:	0	
Post Properties		
Post Type:	Southern Yellow Pine - Round Wooden	
Post Size:	190.8 mm Dia. metric	7.51 in. Dia.
Post Length:	196.0 cm	(497.7 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	BASELINE	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	9.2 m/s	(20.6 mph) (30.2 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









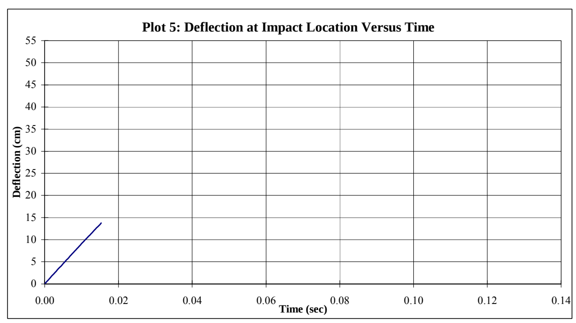
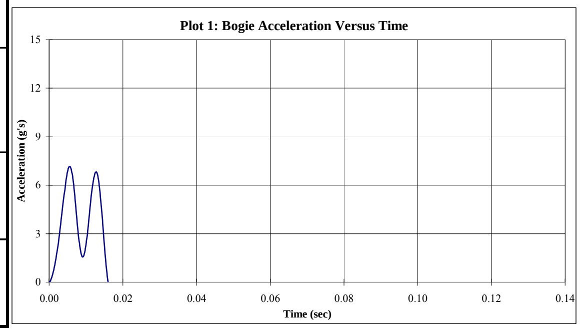
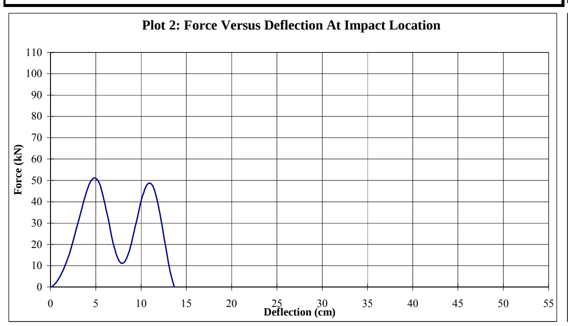


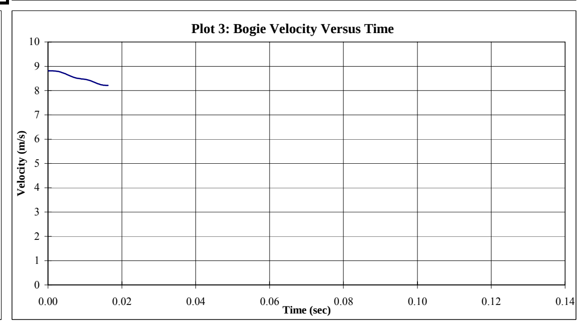
Figure 62. Results of Test No. SY-8

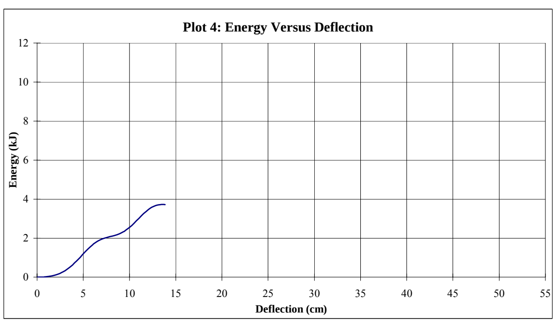
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information		CL Bogie MGS Height	
	Test Number:	SY-9	
	Test Date:	8-Dec-2004	
	Failure Type:	0	
Post Properties			
	Post Type:	Southern Yellow Pine - Round Wooden	
	Post Size:	190.8 mm Dia. metric	7.52 in. Dia.
	Post Length:	197.4 cm	(501.5 cm)
	Embedment Depth:	101.6 cm	(258.1 cm)
	Category:	BASELINE	
Soil Properties			
	Gradation:	NA	
	Moisture Content:	NA	
	Compaction Method:	NA	
	Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties			
	Impact Velocity:	8.8 m/s	(19.7 mph) (28.9 fps)
	Impact Location:	63.2 cm	(24.9 in) above groundline
	Bogie Mass:	728 kg	(1605 lbf)
Data Acquired			
	Accelerometer Data:	EDR-3	
	Camera Data:	Side View-DV and Photron	









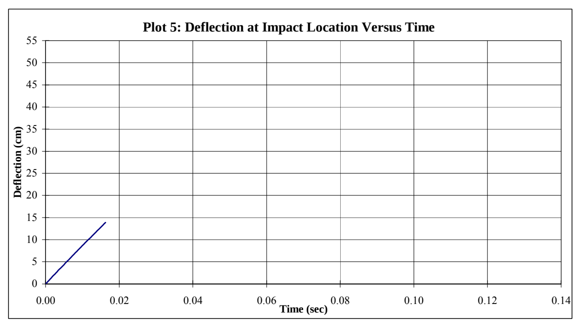
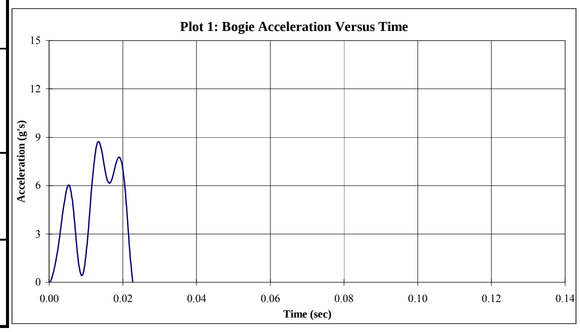


Figure 63. Results of Test No. SY-9

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	SY-10		
Test Date:	9-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	188.7 mm Dia.	metric	7.43 in. Dia.
Post Length:	197.6	cm	(501.9 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	BASELINE		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	8.7 m/s	(19.4 mph)	(28.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		



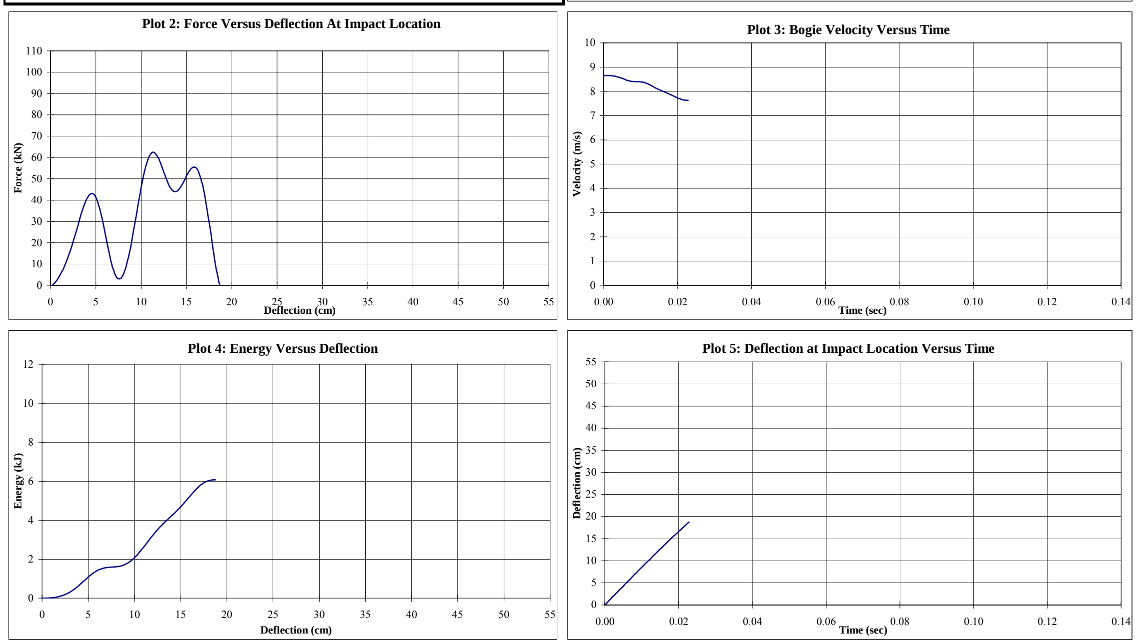
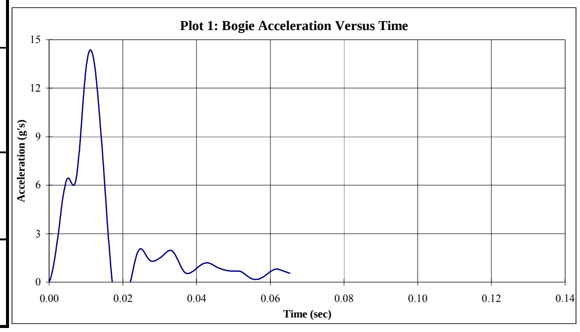
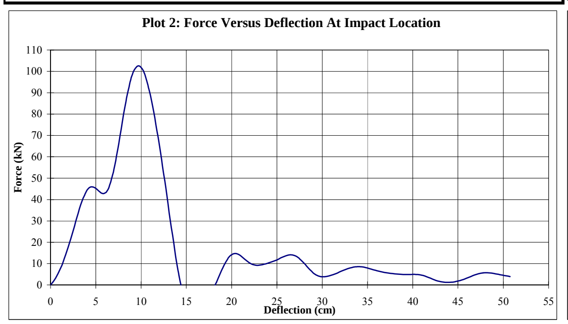


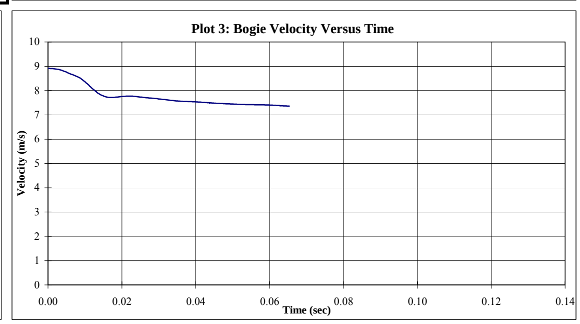
Figure 64. Results of Test No. SY-10

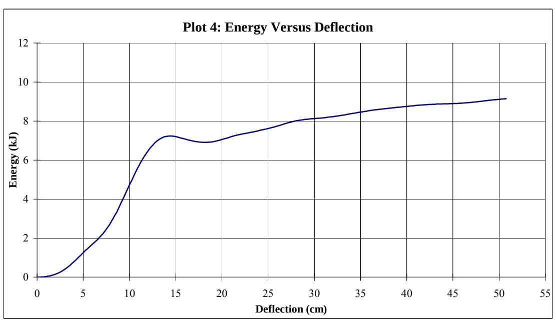
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	SY-11		
Test Date:	9-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	184.9 mm Dia.	metric	7.28 in. Dia.
Post Length:	186.9	cm	(474.7 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.9 mph)	(29.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









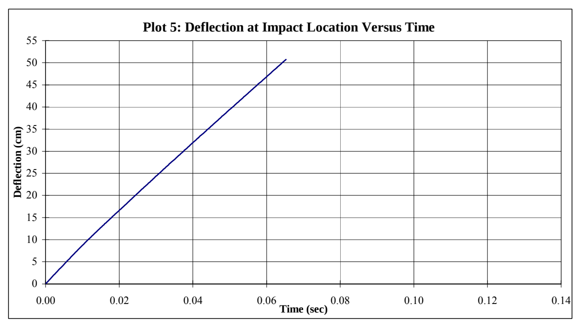
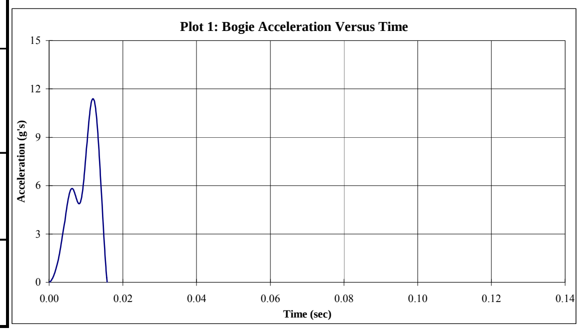


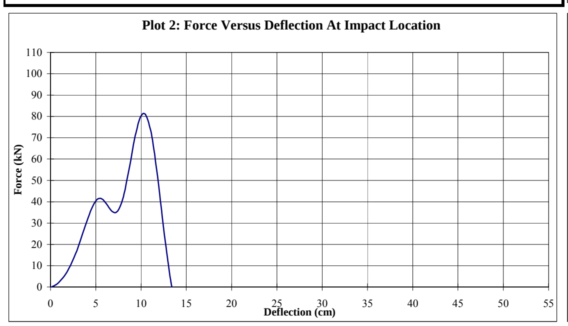
Figure 65. Results of Test No. SY-11

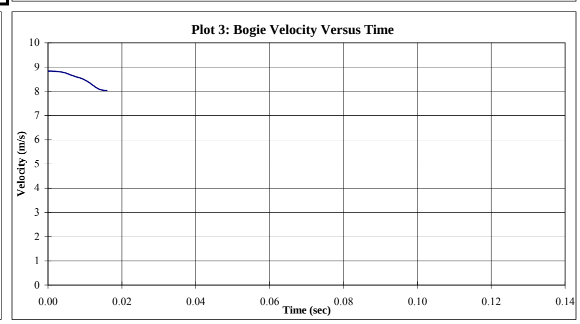
Midwest Roadside Safety Facility

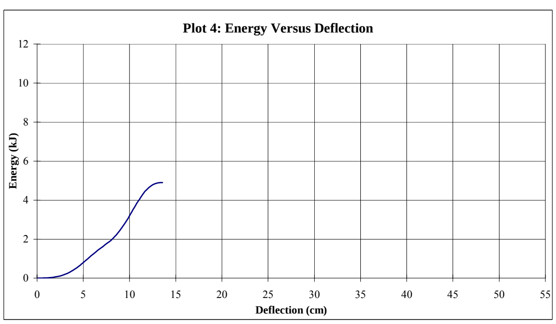
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	SY-12		
Test Date:	9-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	185.2 mm Dia.	metric	7.29 in. Dia.
Post Length:	187.9 cm		(477.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3		NA
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(29.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









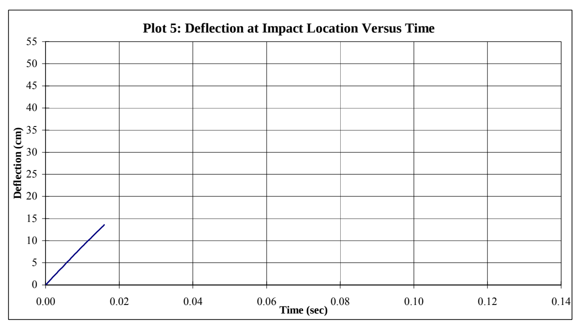


Figure 66. Results of Test No. SY-12

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	SY-13		
Test Date:	9-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	180.9 mm Dia.	metric	7.12 in. Dia.
Post Length:	199.9 cm		(507.8 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA kg/m^3		NA
Bogie Properties			
Impact Velocity:	8.6 m/s	(19.3 mph)	(28.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		

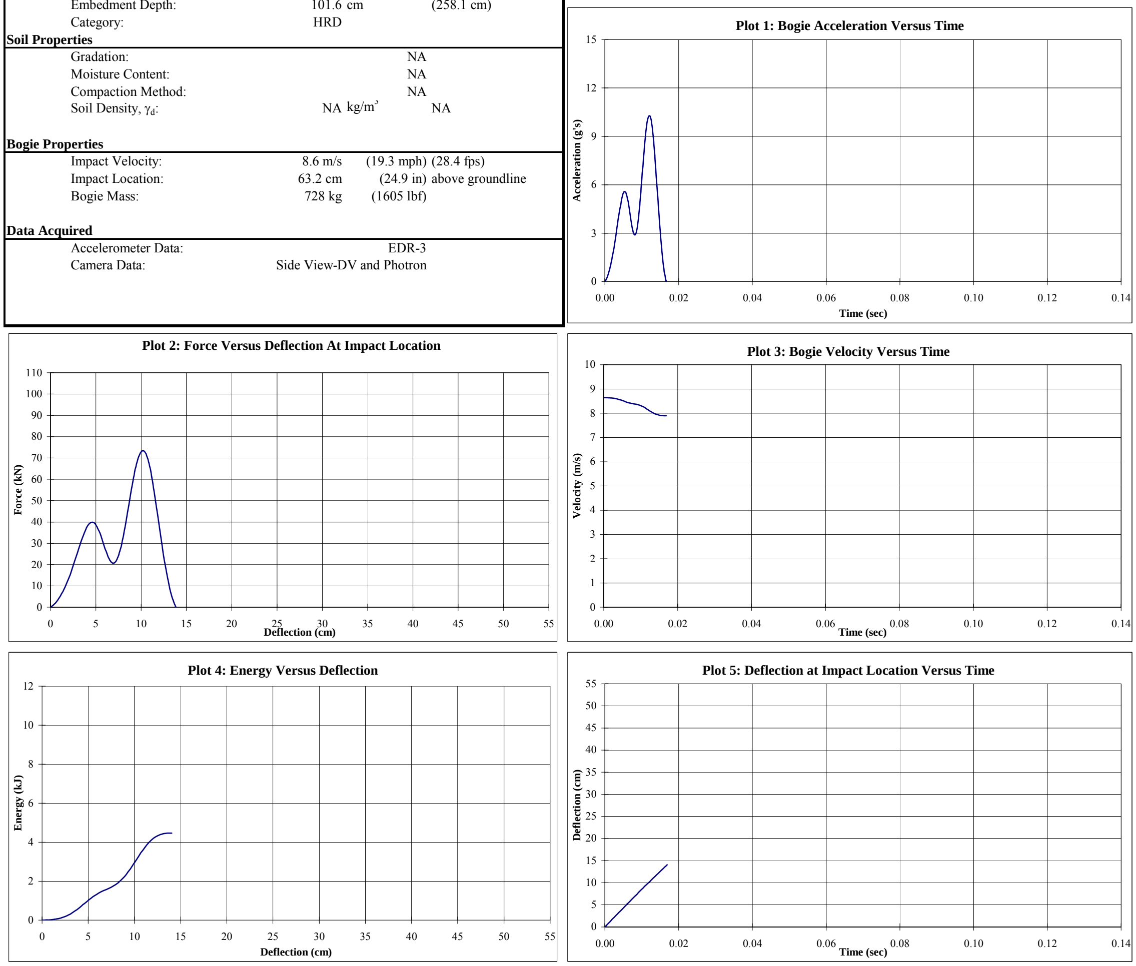
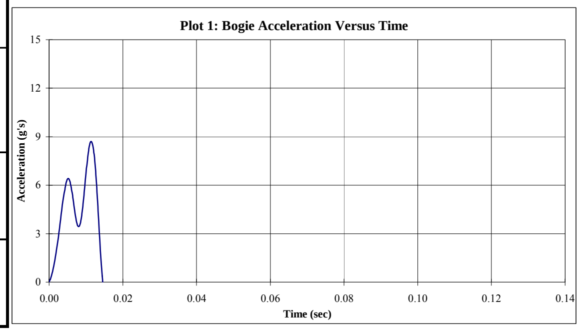
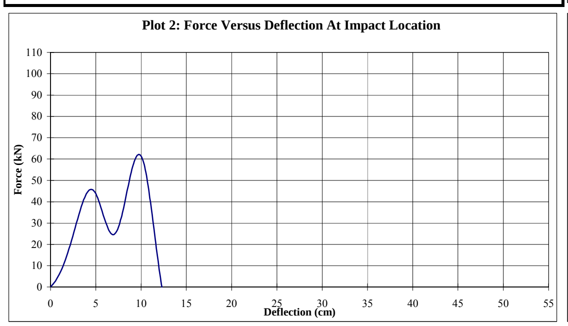


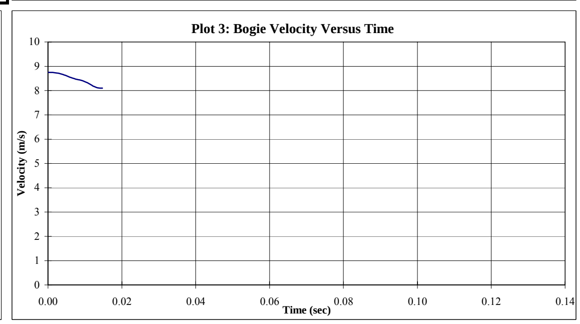
Figure 67. Results of Test No. SY-13

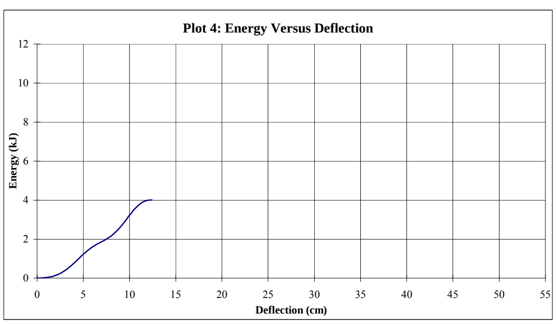
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	SY-14		
Test Date:	9-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	189.7 mm Dia.	metric	7.47 in. Dia.
Post Length:	197.6 cm		(502.0 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3		NA
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.6 mph)	(28.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









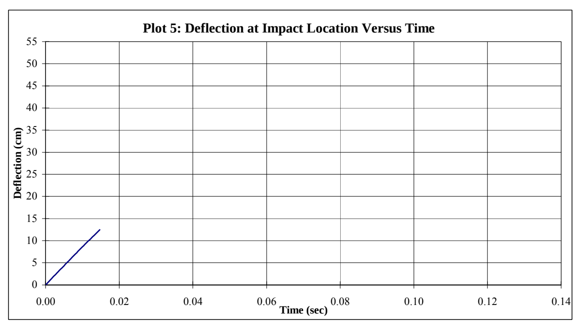
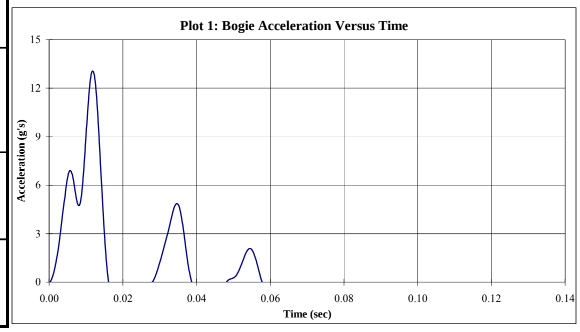


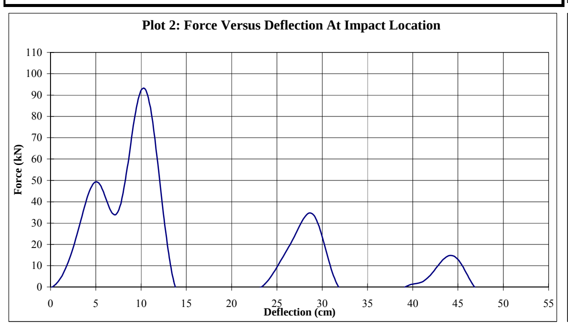
Figure 68. Results of Test No. SY-14

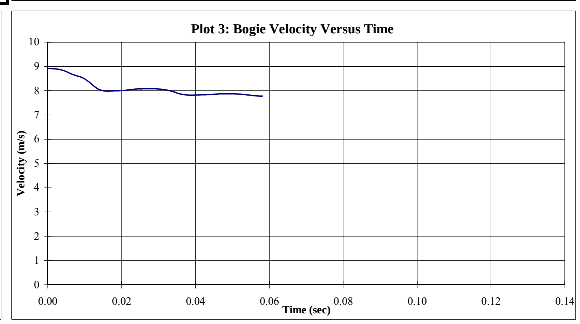
Midwest Roadside Safety Facility

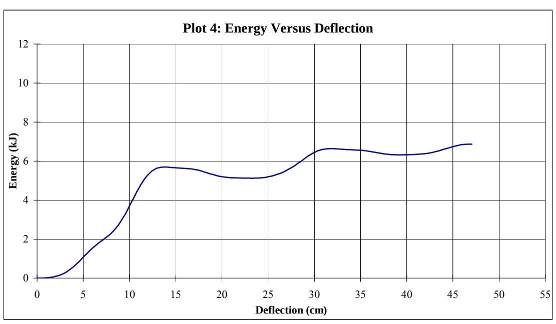
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	SY-15		
Test Date:	9-Dec-2004		
Failure Type:	0		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	183.6 mm Dia.	metric	7.23 in. Dia.
Post Length:	197.3	cm	(501.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.9 mph)	(29.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









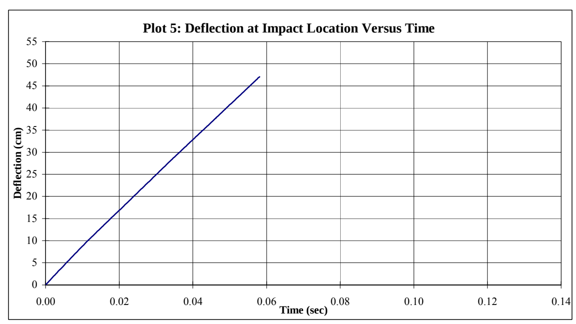
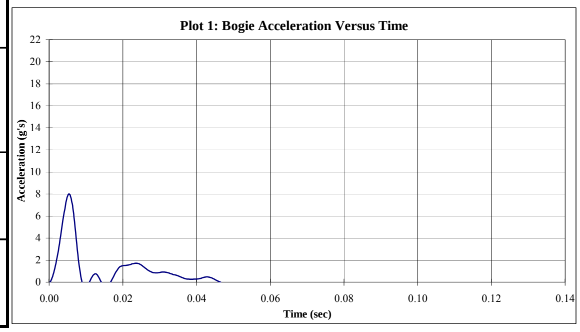


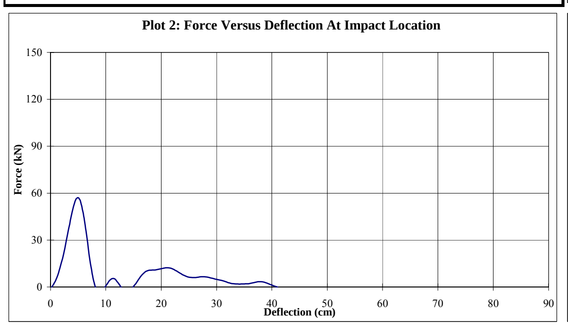
Figure 69. Results of Test No. SY-15

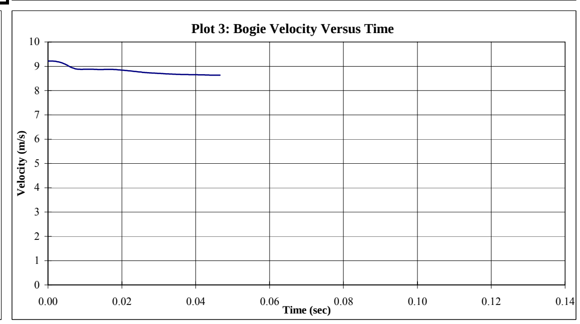
Midwest Roadside Safety Facility

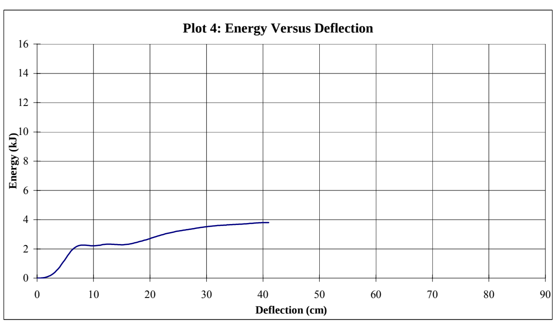
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-1		
Test Date:	12-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	209.8 mm Dia.	metric	8.26 in. Dia.
Post Length:	198.1	cm	(503.1 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	BASELINE		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.6 mph)	(30.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









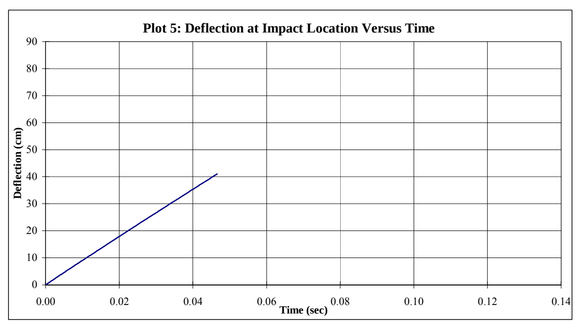
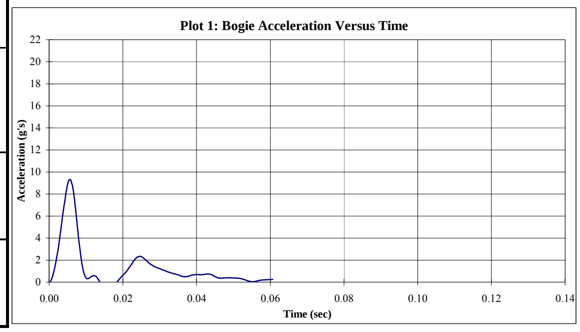
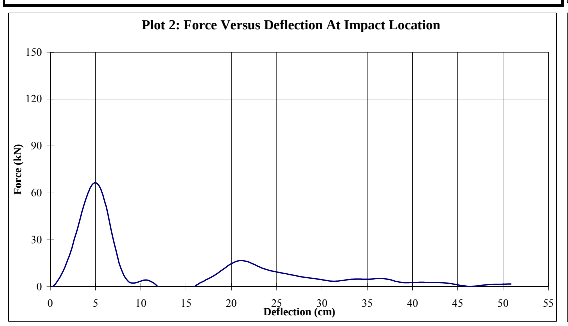


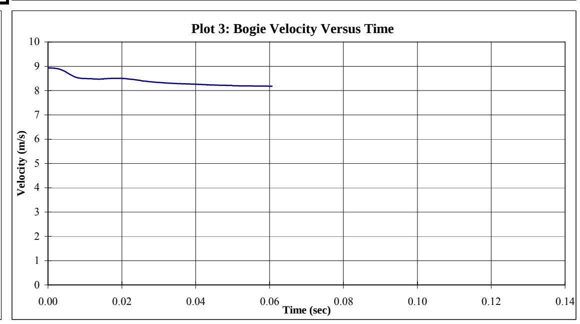
Figure 70. Results of Test No. PP-1

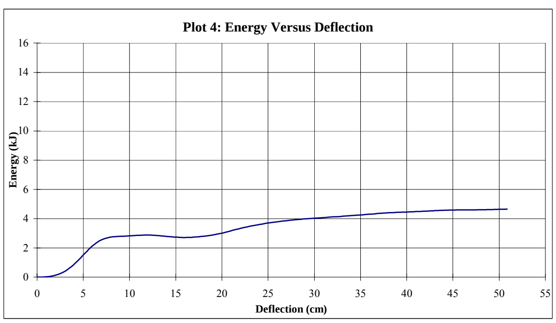
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-2		
Test Date:	12-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	228.3 mm Dia.	metric	8.99 in. Dia.
Post Length:	198.2 cm		(503.5 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	BASELINE		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









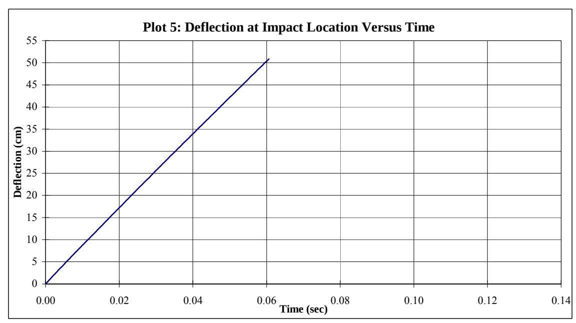
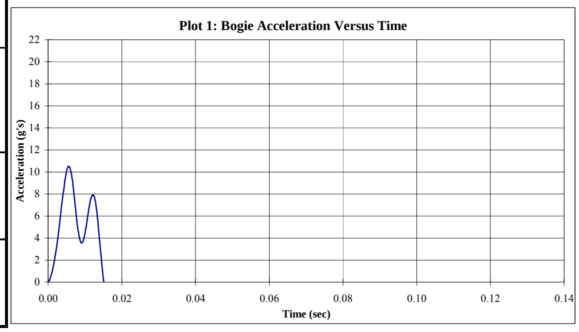
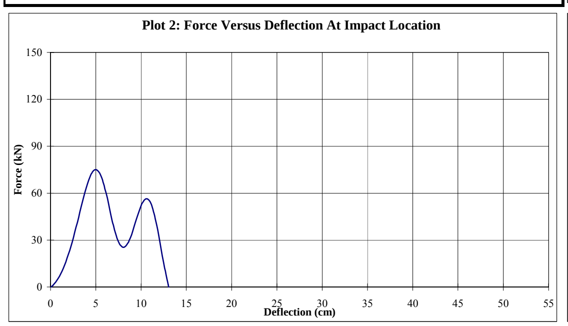


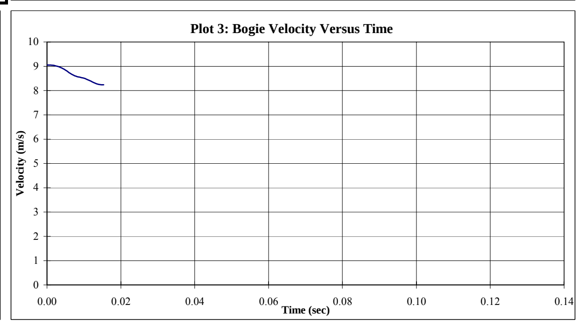
Figure 71. Results of Test No. PP-2

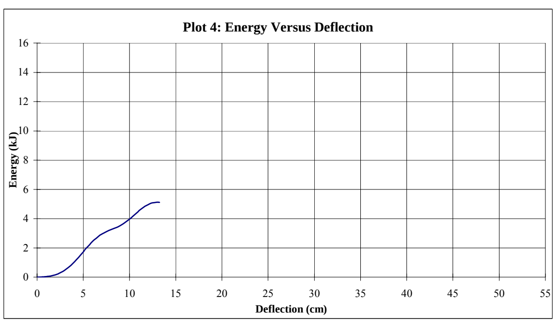
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information		CL Bogie MGS Height	
	Test Number:	PP-3	
	Test Date:	12-Nov-2004	
	Failure Type:	0	
Post Properties			
	Post Type:	Ponderosa Pine - Round Wooden	
	Post Size:	224.0 mm Dia. metric	8.82 in. Dia.
	Post Length:	198.2 cm	(503.5 cm)
	Embedment Depth:	101.6 cm	(258.1 cm)
	Category:	BASELINE	
Soil Properties			
	Gradation:	NA	
	Moisture Content:	NA	
	Compaction Method:	NA	
	Soil Density, γ_d:	NA kg/m³	NA
Bogie Properties			
	Impact Velocity:	9.0 m/s	(20.2 mph) (29.7 fps)
	Impact Location:	63.2 cm	(24.9 in) above groundline
	Bogie Mass:	728 kg	(1605 lbf)
Data Acquired			
	Accelerometer Data:	EDR-3	
	Camera Data:	Side View-DV and Photron	









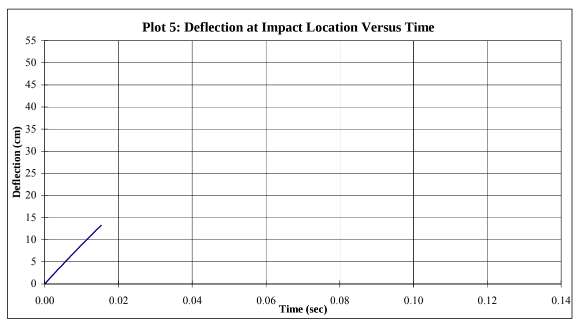
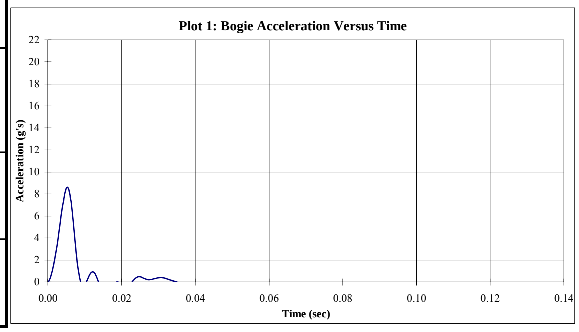
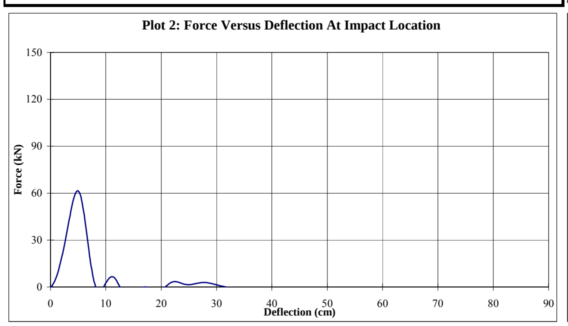


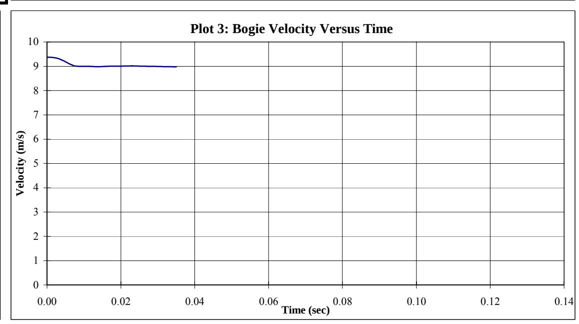
Figure 72. Results of Test No. PP-3

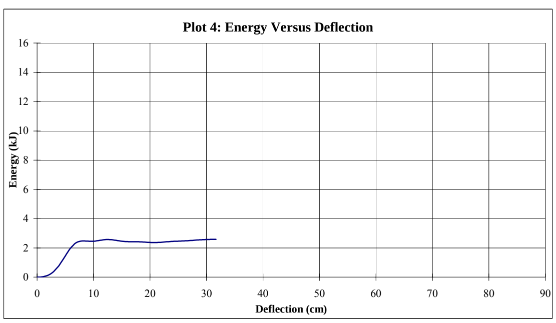
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-4		
Test Date:	12-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	225.8 mm Dia.	metric	8.89 in. Dia.
Post Length:	197.8 cm		(502.5 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	BASELINE		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.4 m/s	(21.0 mph)	(30.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









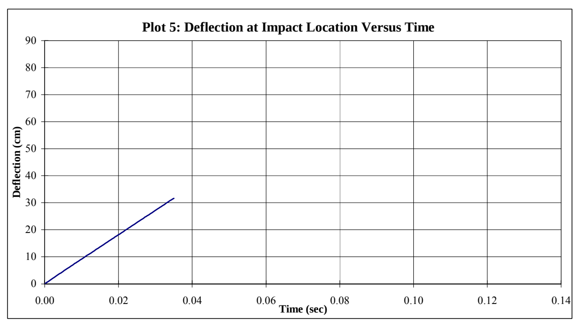
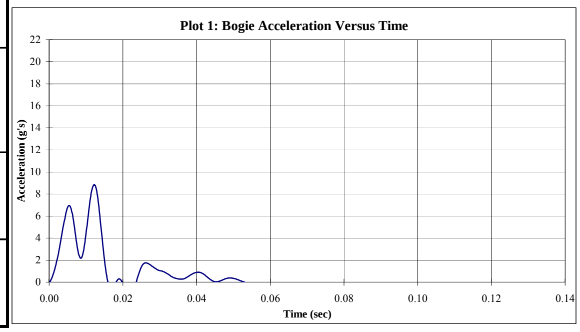
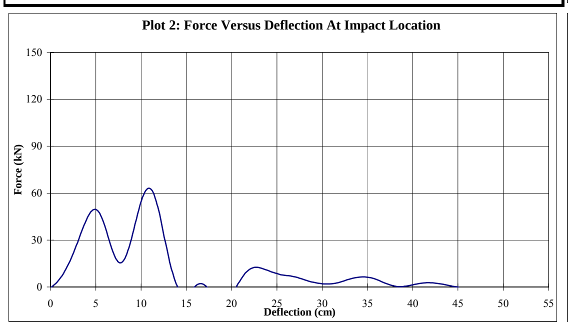


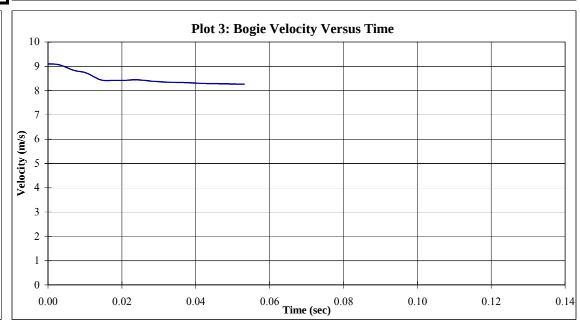
Figure 73. Results of Test No. PP-4

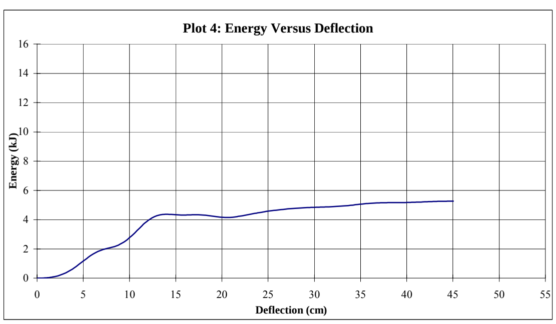
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information		CL Bogie MGS Height	
	Test Number:	PP-5	
	Test Date:	15-Nov-2004	
	Failure Type:	0	
Post Properties			
	Post Type:	Ponderosa Pine - Round Wooden	
	Post Size:	212.9 mm Dia. metric	8.38 in. Dia.
	Post Length:	198.1 cm	(503.2 cm)
	Embedment Depth:	101.6 cm	(258.1 cm)
	Category:	BASELINE	
Soil Properties			
	Gradation:	NA	
	Moisture Content:	NA	
	Compaction Method:	NA	
	Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties			
	Impact Velocity:	9.1 m/s	(20.4 mph) (29.8 fps)
	Impact Location:	63.2 cm	(24.9 in) above groundline
	Bogie Mass:	728 kg	(1605 lbf)
Data Acquired			
	Accelerometer Data:	EDR-3	
	Camera Data:	Side View-DV and Photron	









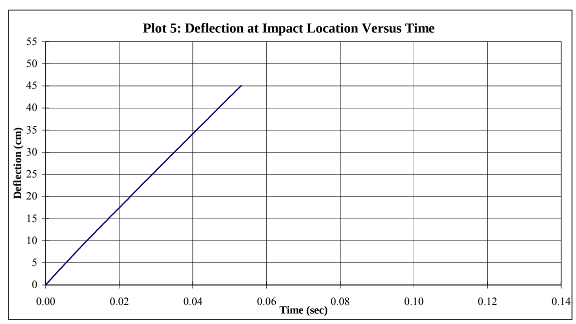
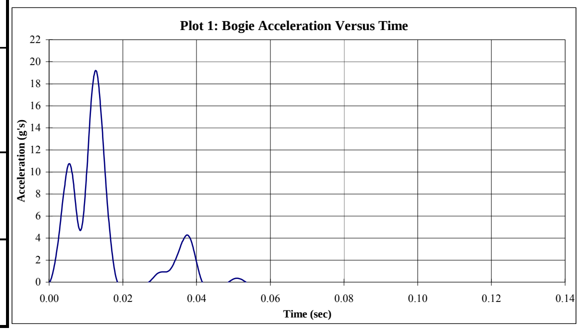


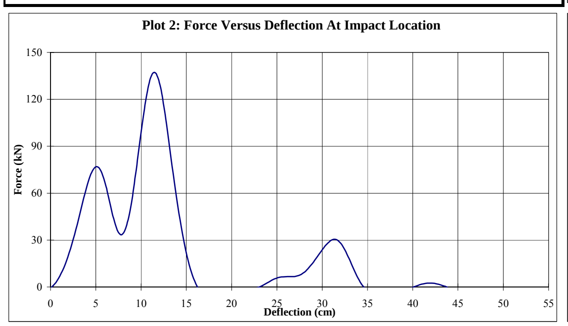
Figure 74. Results of Test No. PP-5

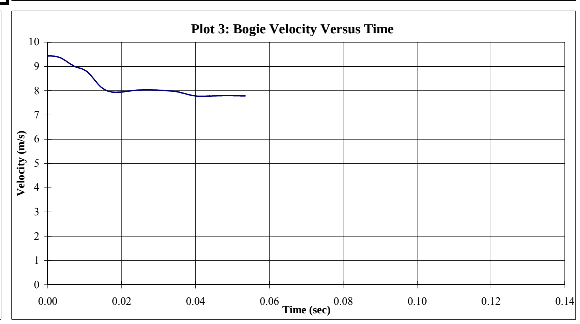
Midwest Roadside Safety Facility

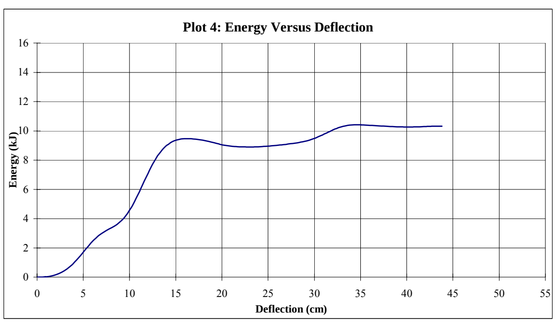
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-6		
Test Date:	15-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	224.79 mm Dia.	metric	8.85 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.4 m/s	(21.1 mph)	(31.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









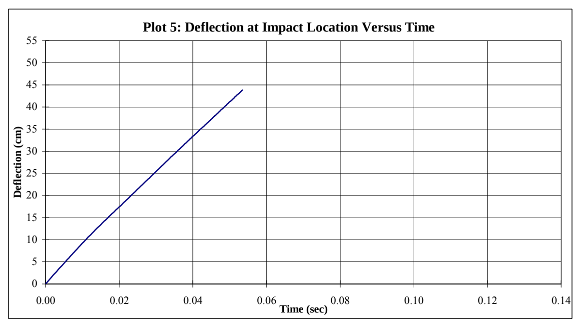
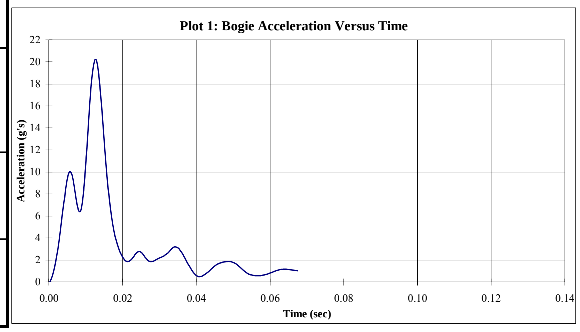
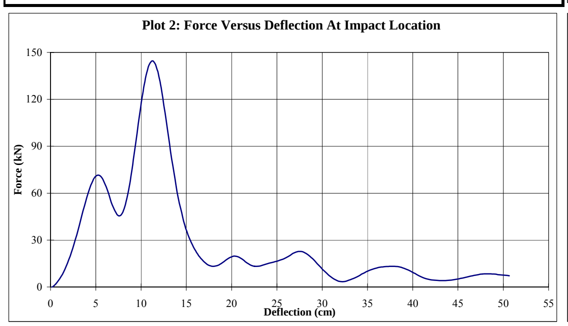


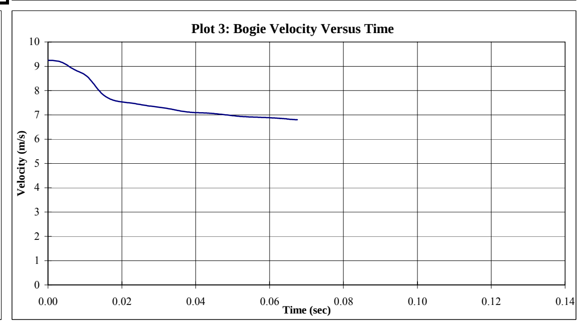
Figure 75. Results of Test No. PP-6

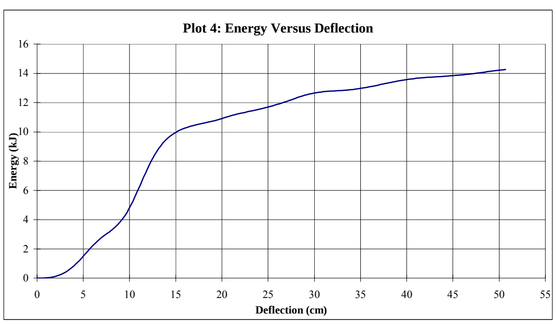
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-7		
Test Date:	15-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	227.08 mm Dia.	metric	8.94 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.7 mph)	(30.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:			EDR-3
Camera Data:	Side View-DV and Photron		









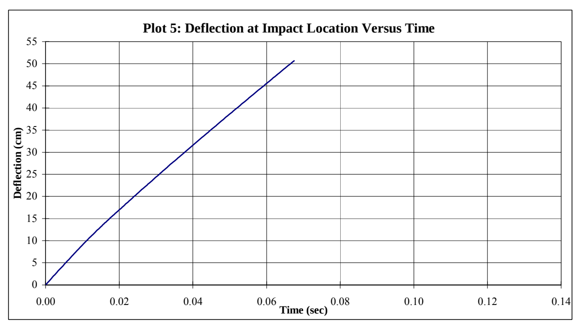
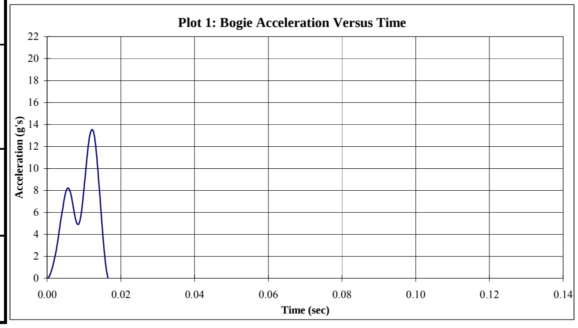
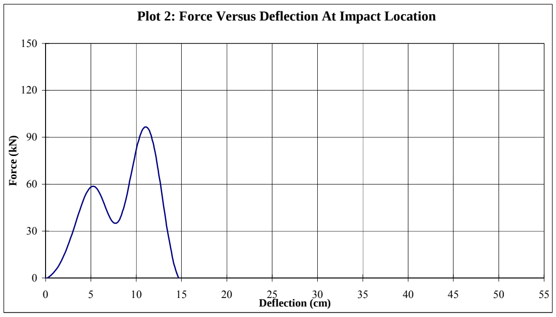


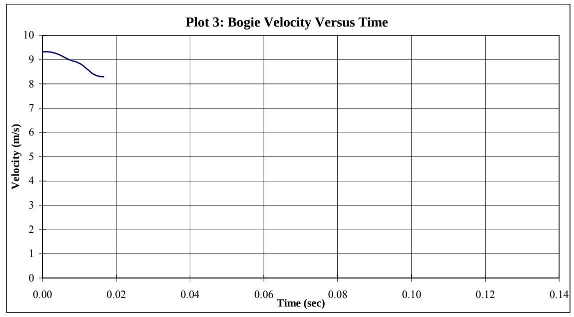
Figure 76. Results of Test No. PP-7

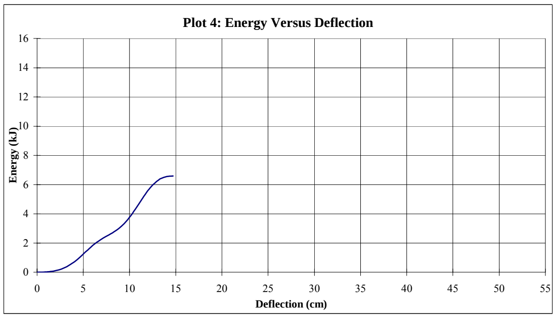
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-8		
Test Date:	15-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	225.8 mm Dia.	metric	8.89 in. Dia.
Post Length:	198.3 cm		(503.7 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.9 mph)	(30.6 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









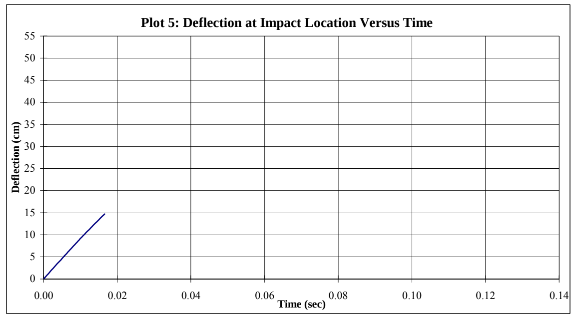
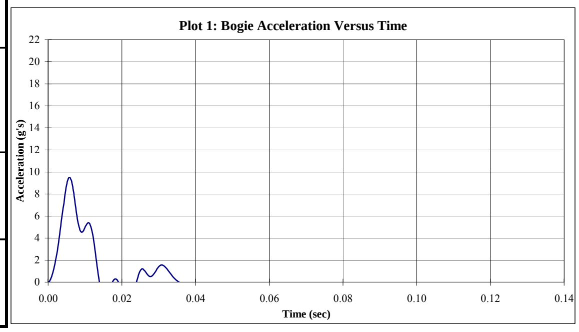


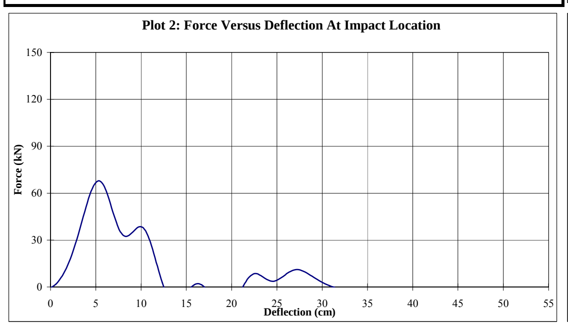
Figure 77. Results of Test No. PP-8

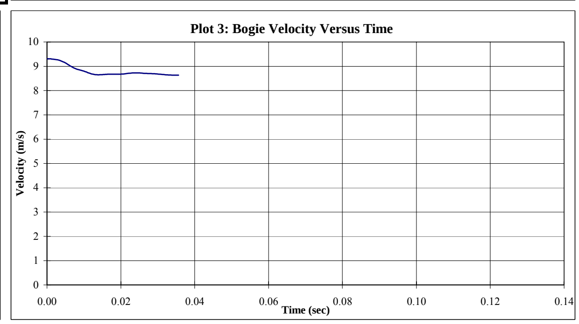
Midwest Roadside Safety Facility

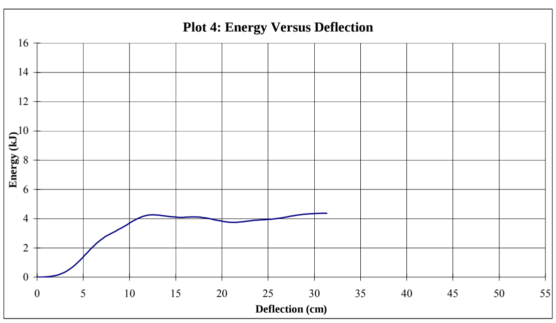
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	PP-9	
Test Date:	15-Nov-2004	
Failure Type:	0	
Post Properties		
Post Type:	Ponderosa Pine - Round Wooden	
Post Size:	227.3 mm Dia. metric	8.95 in. Dia.
Post Length:	198.0 cm	(502.8 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	HRD	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	9.3 m/s	(20.8 mph) (30.5 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









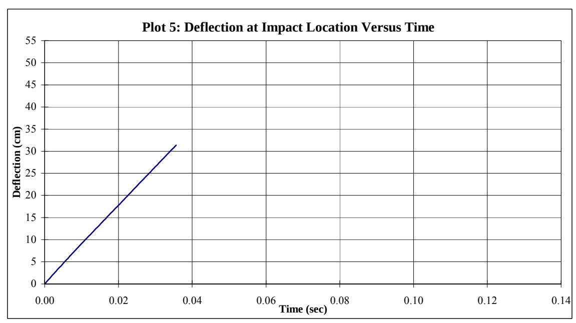
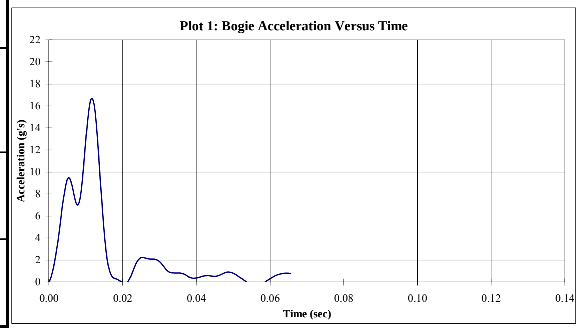
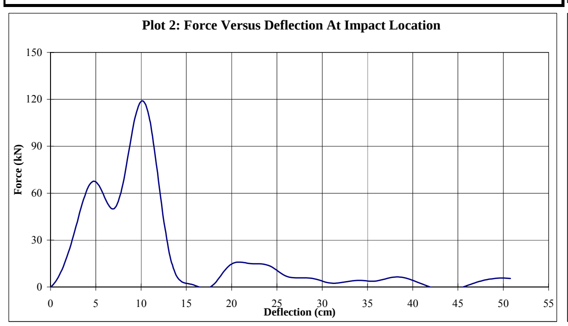


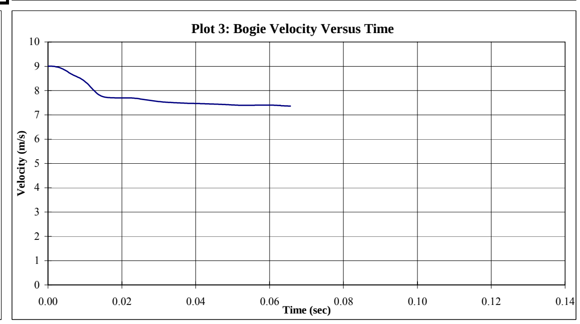
Figure 78. Results of Test No. PP-9

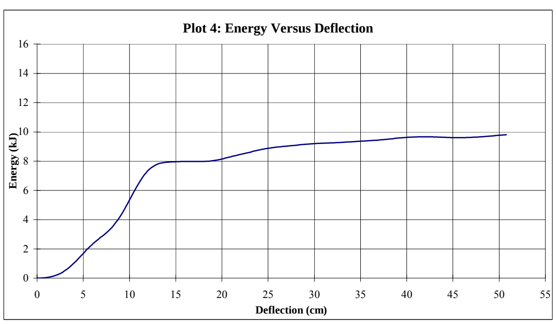
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-10		
Test Date:	15-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	224.0 mm Dia.	metric	8.82 in. Dia.
Post Length:	198.2 cm		(503.4 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









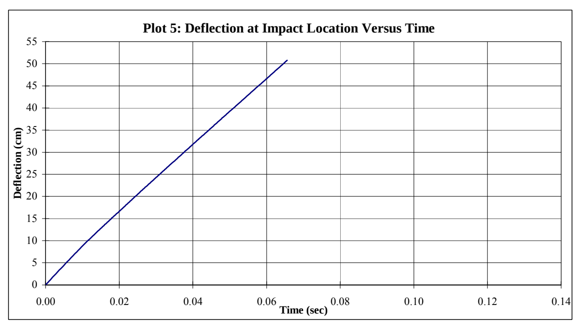
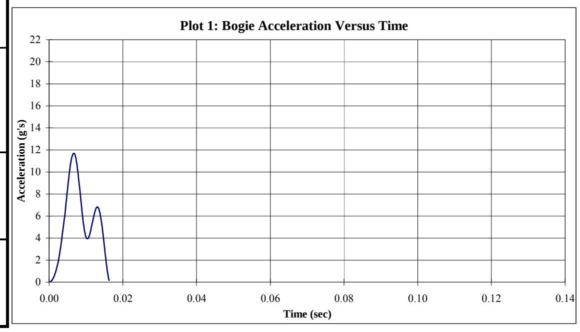


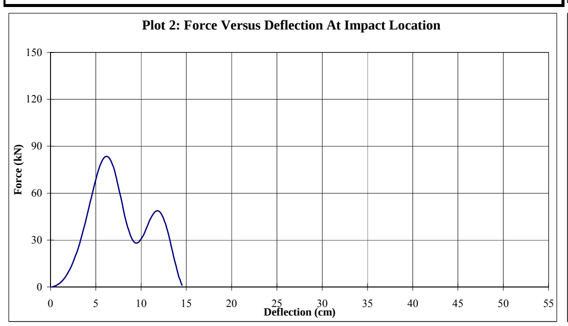
Figure 79. Results of Test No. PP-10

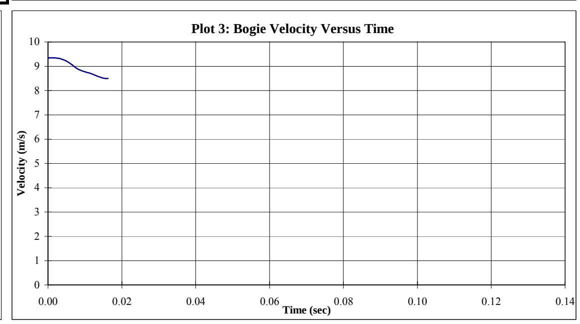
Midwest Roadside Safety Facility

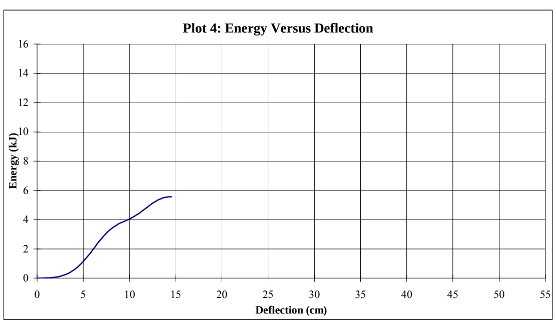
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-11		
Test Date:	15-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	229.9 mm Dia.	metric	9.05 in. Dia.
Post Length:	198.2	cm	(503.4 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.9 mph)	(30.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:		Side View-DV and Photron	









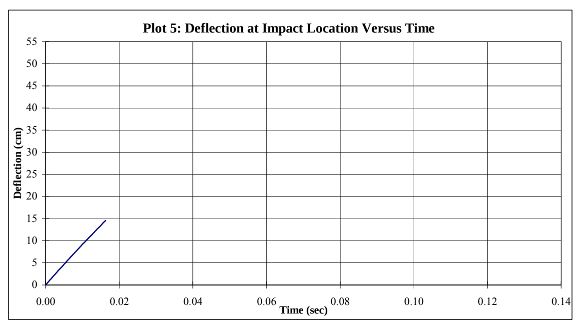
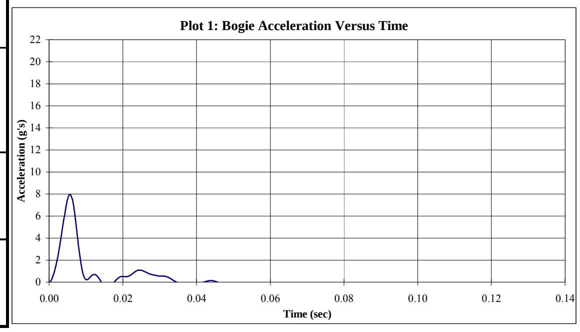
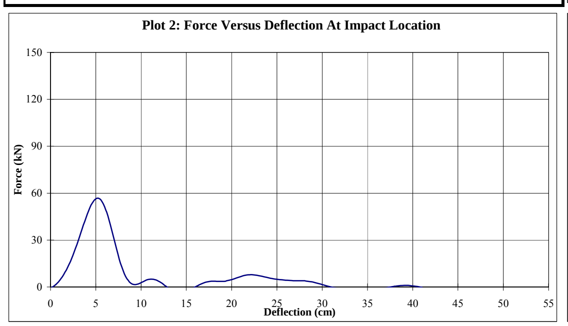


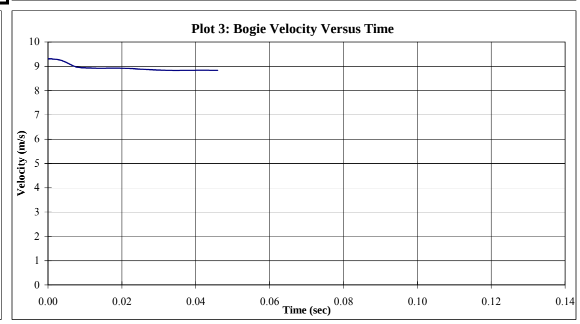
Figure 80. Results of Test No. PP-11

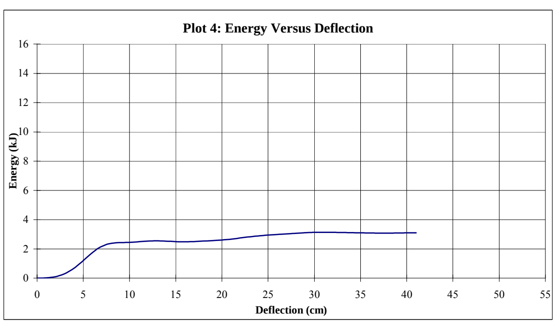
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-12		
Test Date:	17-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	204.7 mm Dia.	metric	8.06 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.8 mph)	(30.5 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









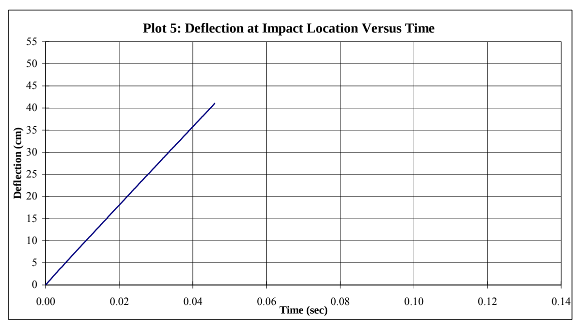
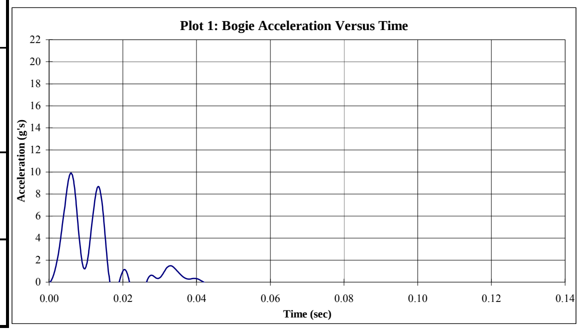


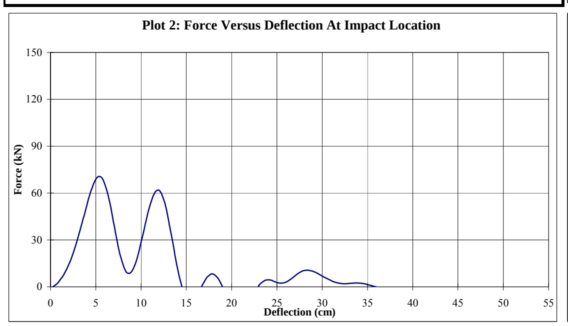
Figure 81. Results of Test No. PP-12

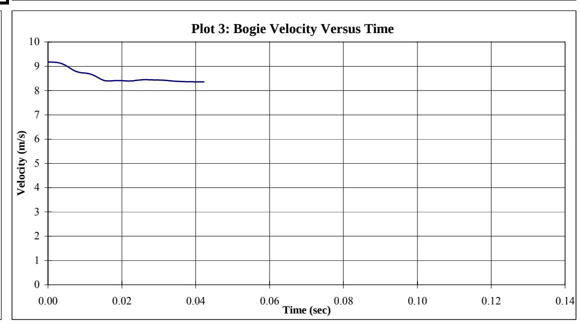
Midwest Roadside Safety Facility

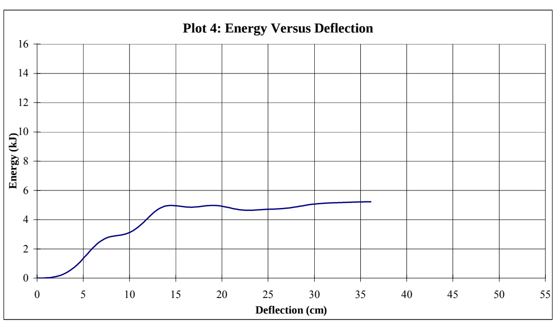
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-13		
Test Date:	17-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	225.0 mm Dia. metric	8.86 in. Dia.	
Post Length:	198.2 cm	(503.5 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	KNOTS		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline	
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









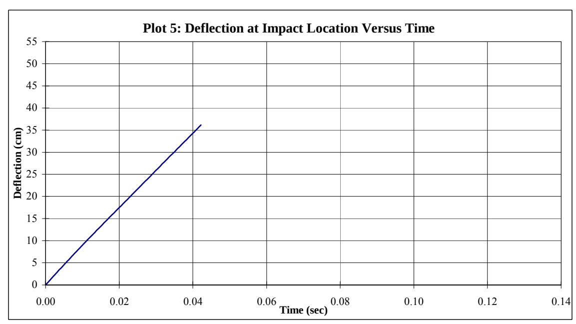
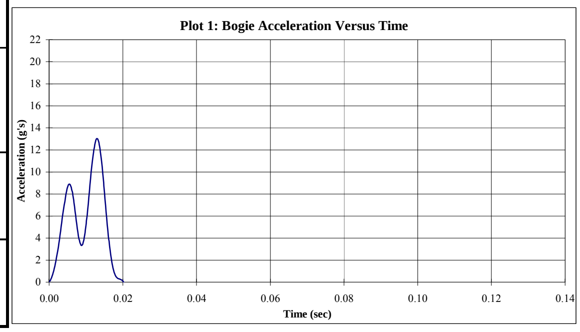
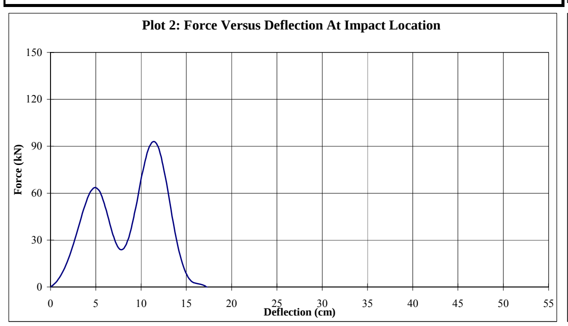


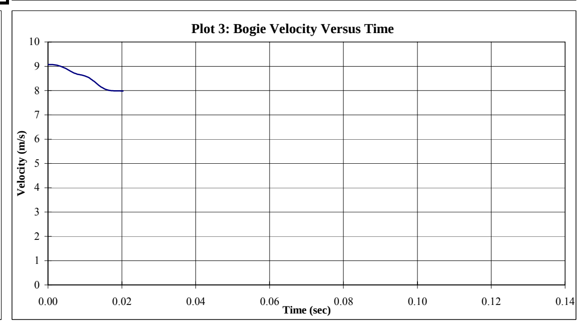
Figure 82. Results of Test No. PP-13

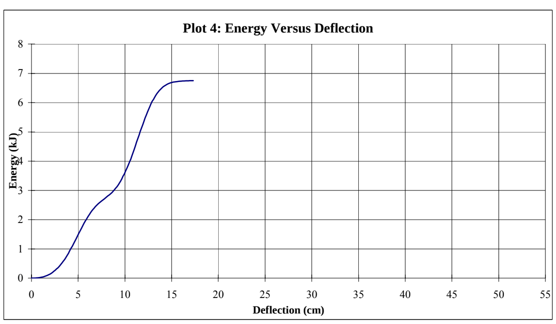
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-14		
Test Date:	17-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	224.3 mm Dia.	metric	8.83 in. Dia.
Post Length:	198.2	cm	(503.4 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.1 m/s	(20.3 mph)	(29.8 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









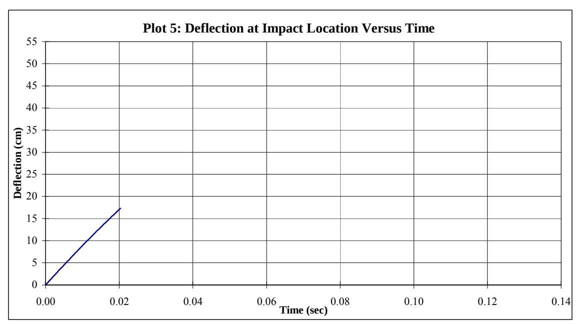
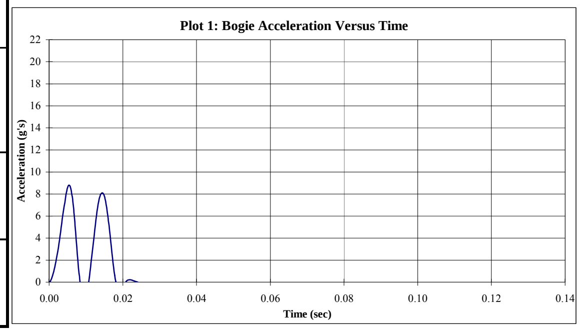
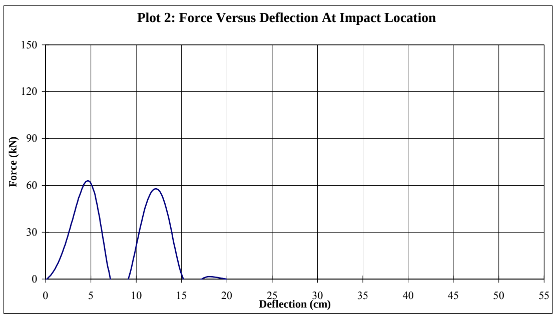


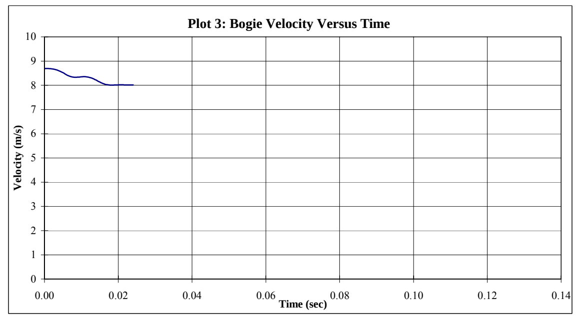
Figure 83. Results of Test No. PP-14

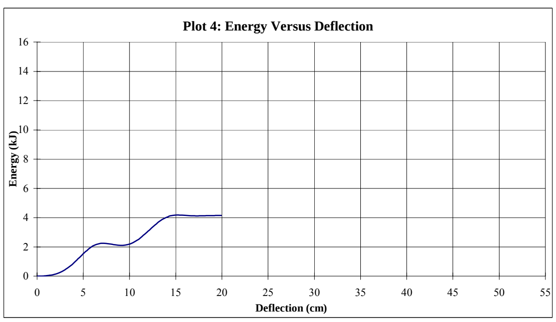
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information		CL Bogie MGS Height	
	Test Number:	PP-15	
	Test Date:	17-Nov-2004	
	Failure Type:	0	
Post Properties			
	Post Type:	Ponderosa Pine - Round Wooden	
	Post Size:	208.8 mm Dia. metric	8.22 in. Dia.
	Post Length:	198.1 cm	(503.2 cm)
	Embedment Depth:	101.6 cm	(258.1 cm)
	Category:	KNOTS	
Soil Properties			
	Gradation:	NA	
	Moisture Content:	NA	
	Compaction Method:	NA	
	Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties			
	Impact Velocity:	8.7 m/s	(19.4 mph) (28.5 fps)
	Impact Location:	63.2 cm	(24.9 in) above groundline
	Bogie Mass:	728 kg	(1605 lbf)
Data Acquired			
	Accelerometer Data:	EDR-3	
	Camera Data:	Side View-DV and Photron	









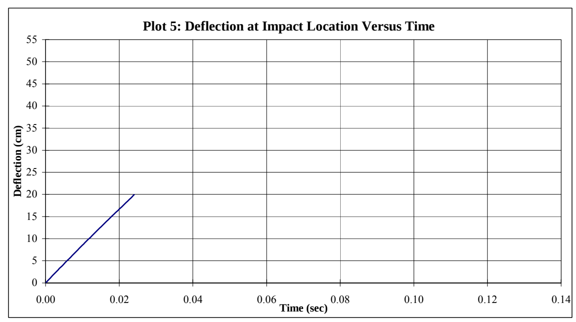
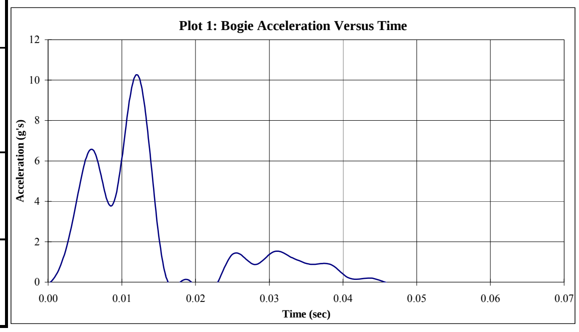


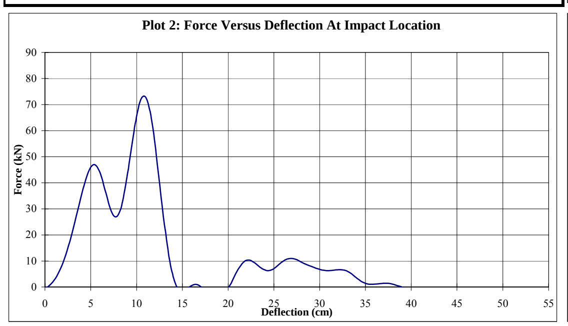
Figure 84. Results of Test No. PP-15

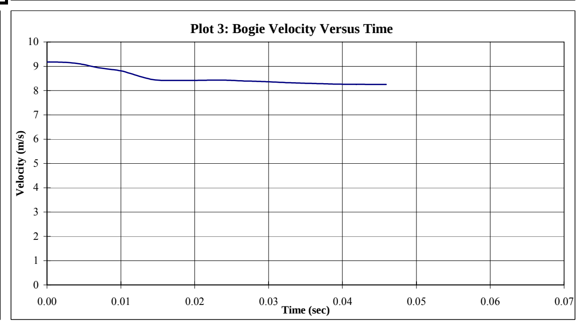
Midwest Roadside Safety Facility

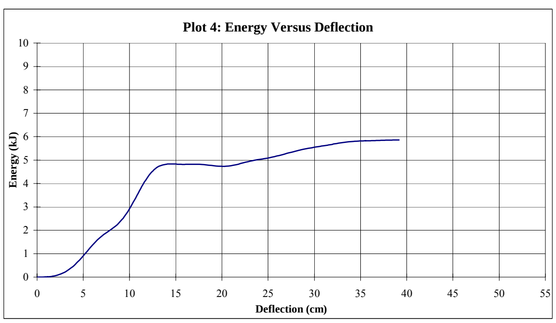
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	DF-1	
Test Date:	9-Nov-2004	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	186.7 mm Dia. metric	7.35 in. Dia.
Post Length:	198.8 cm	(504.8 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	HRD	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m³	NA
Bogie Properties		
Impact Velocity:	9.2 m/s	(20.5 mph) (30.1 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









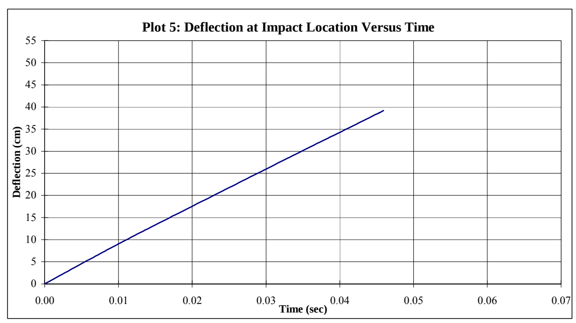
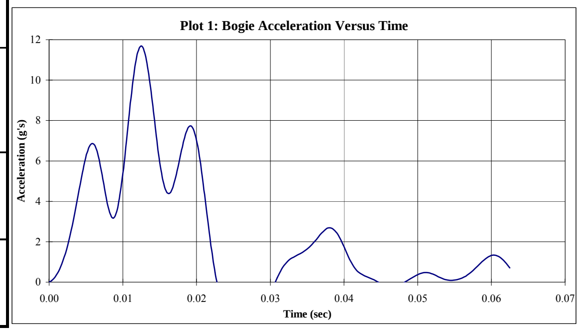
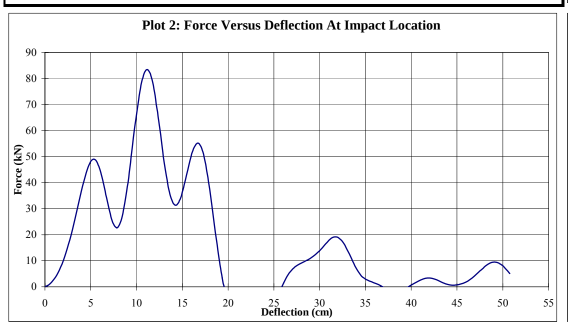


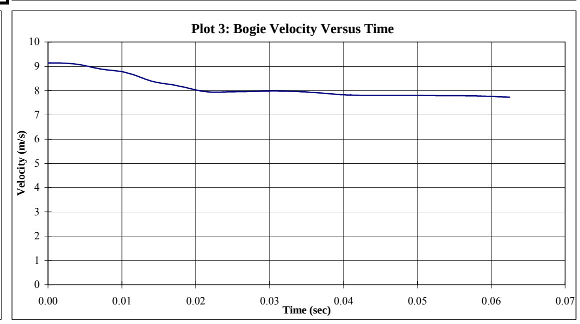
Figure 85. Results of Test No. DF-1

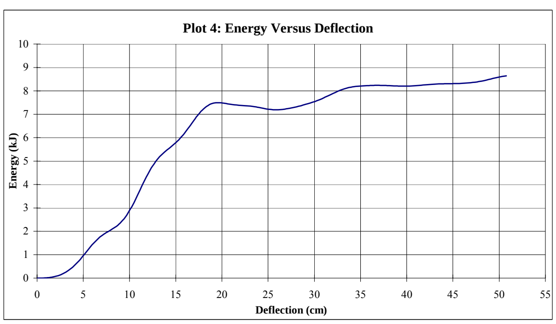
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-2		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia. metric	7.18 in. Dia.	
Post Length:	198.0 cm	(503.0 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	9.1 m/s	(20.4 mph)	(30.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









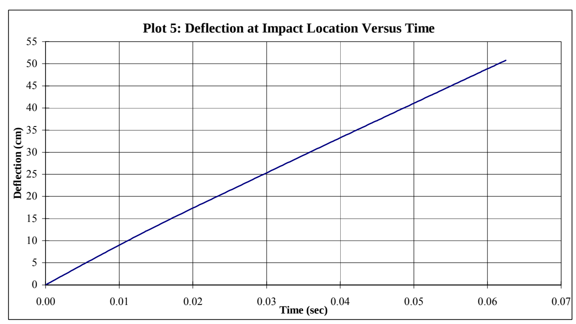
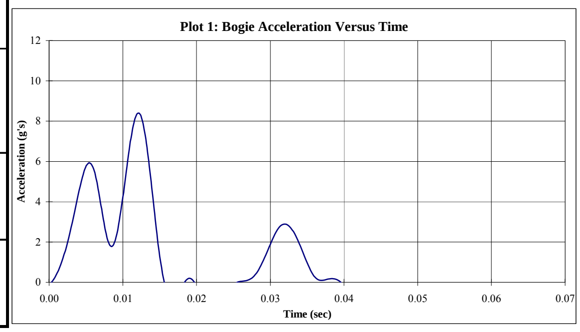
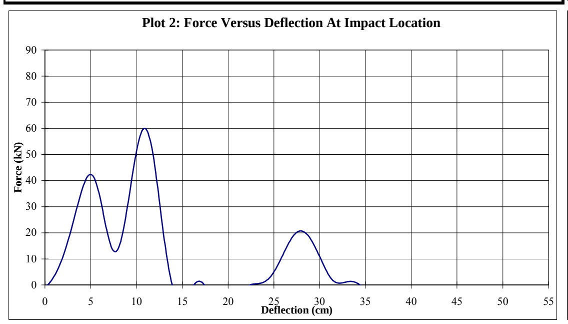


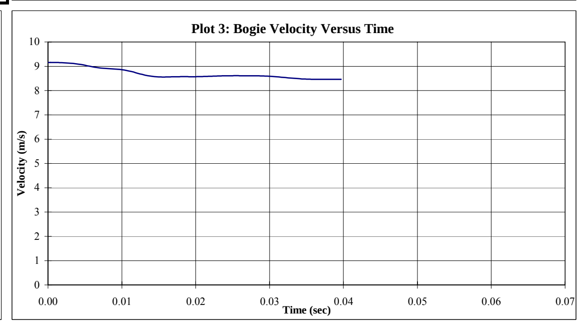
Figure 86. Results of Test No. DF-2

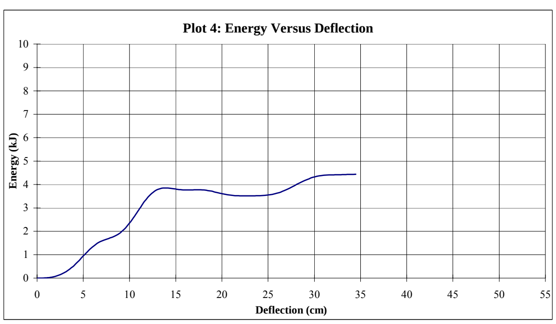
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-3		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia.	metric	7.31 in. Dia.
Post Length:	195.8 cm		(497.3 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









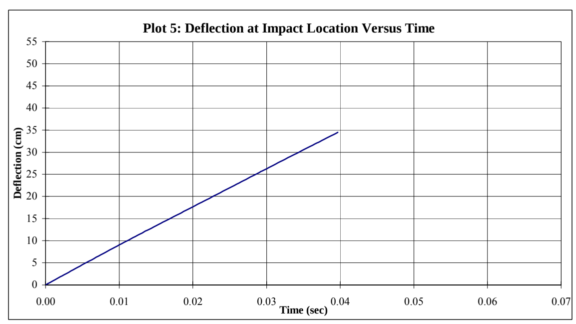
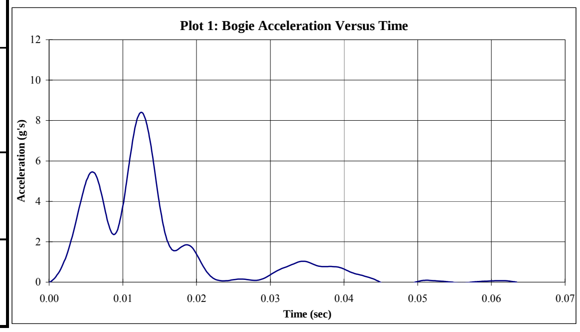
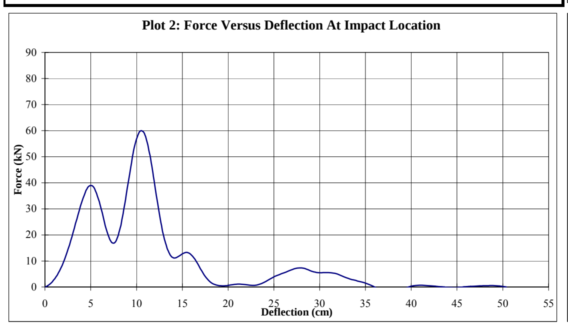


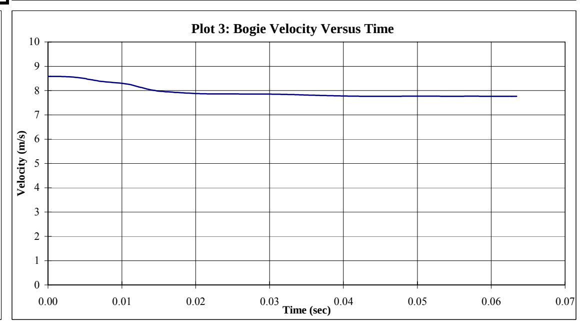
Figure 87. Results of Test No. DF-3

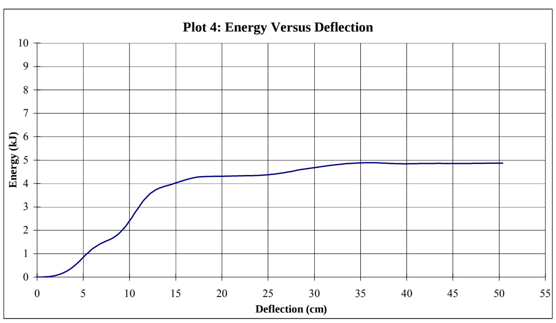
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-4		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia.	metric	7.29 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	8.6 m/s	(19.2 mph)	(28.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









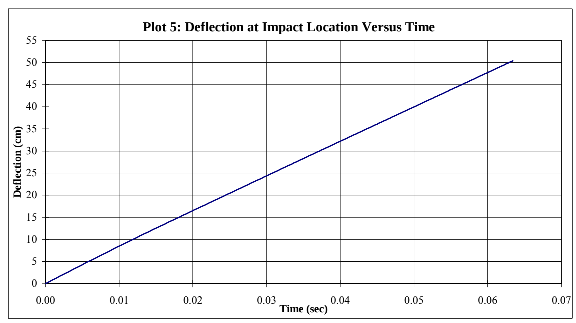
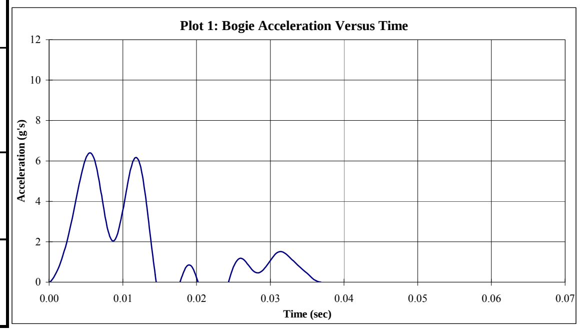
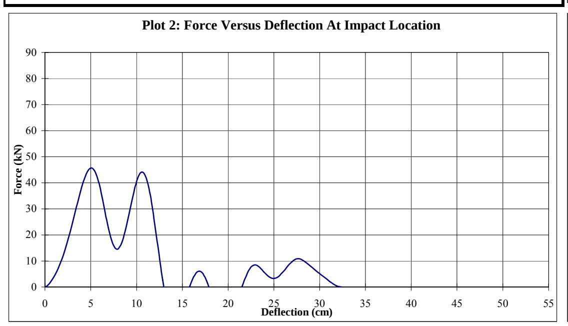


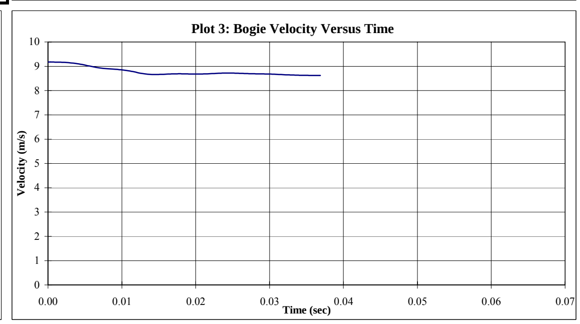
Figure 88. Results of Test No. DF-4

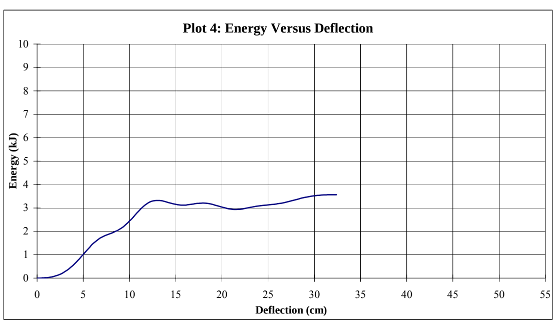
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-5		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia. metric	7.33 in. Dia.	
Post Length:	198.2 cm	(503.5 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









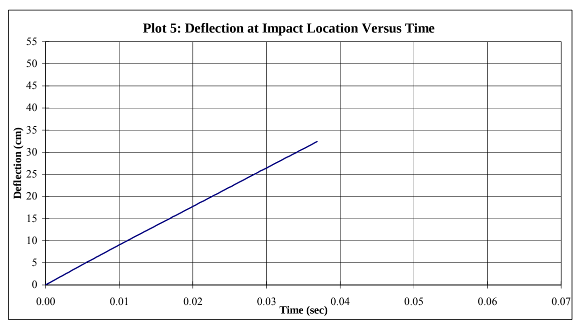
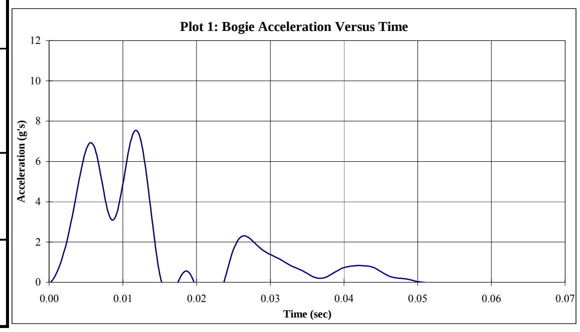
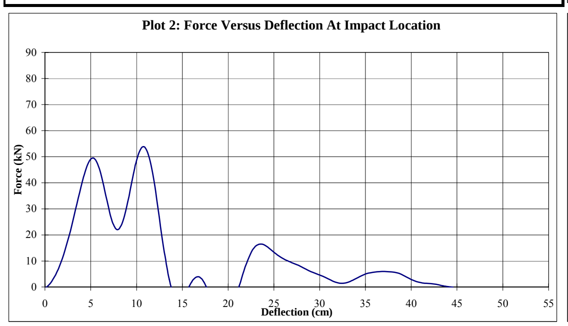


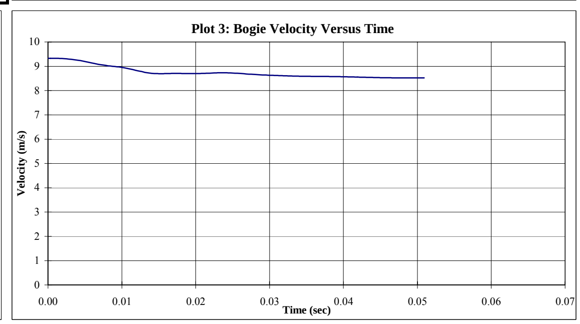
Figure 89. Results of Test No. DF-5

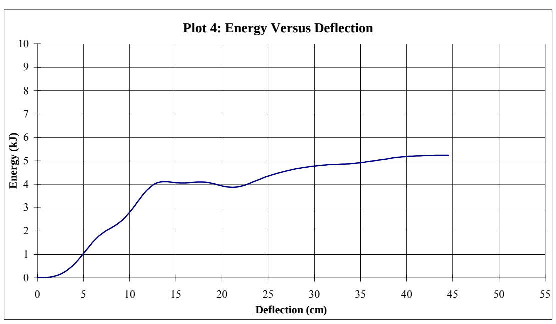
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-6		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia.	metric	7.35 in. Dia.
Post Length:	198.2	cm	(503.5 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.9 mph)	(30.6 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









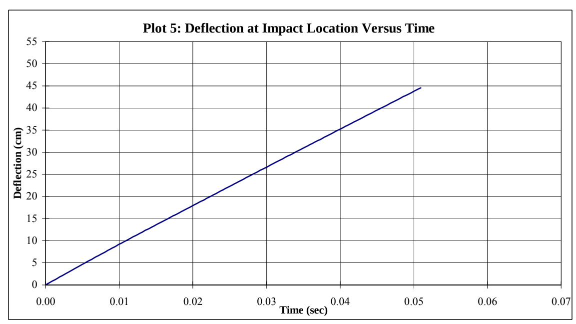
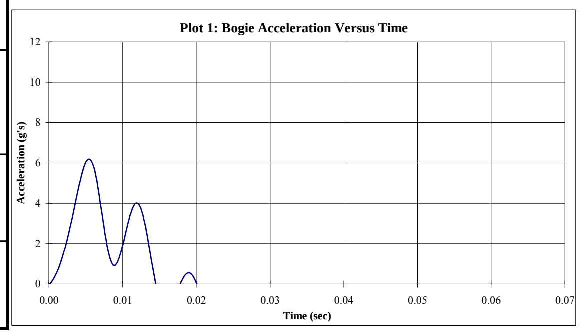


Figure 90. Results of Test No. DF-6

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-7		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia. metric	7.31 in. Dia.	
Post Length:	196.9 cm	(500.1 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	KNOTS		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.1 mph)	(29.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		



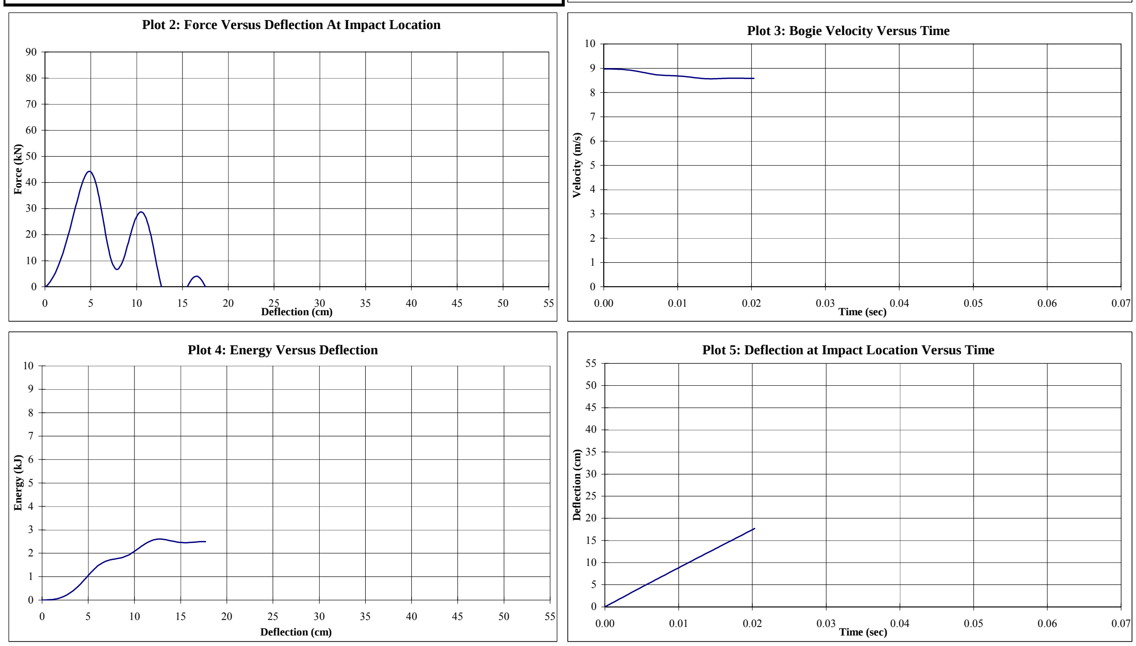
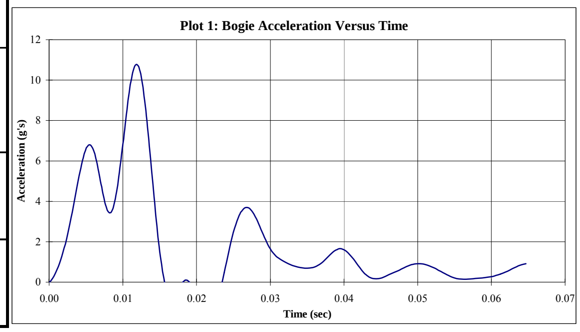


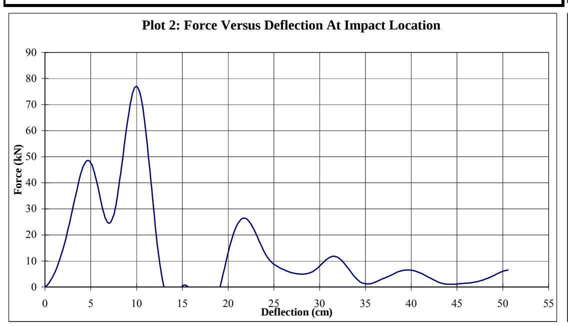
Figure 91. Results of Test No. DF-7

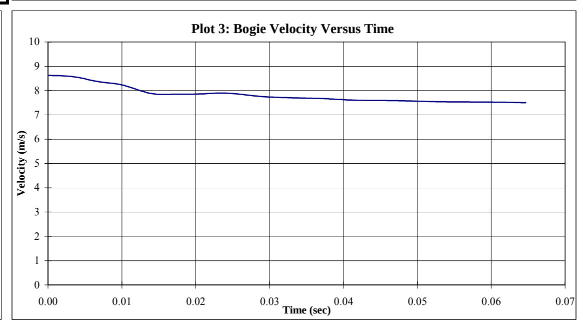
Midwest Roadside Safety Facility

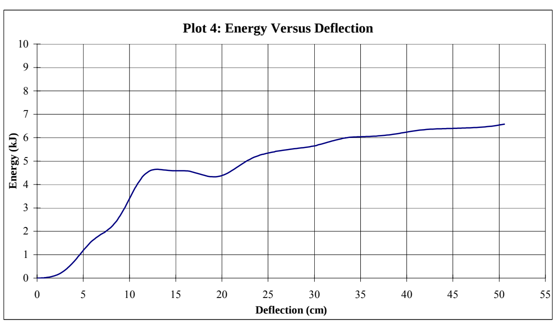
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	DF-8	
Test Date:	9-Nov-2004	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	182.4 mm Dia. metric	7.27 in. Dia.
Post Length:	198.1 cm	(503.2 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	KNOTS	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	8.6 m/s	(19.3 mph) (28.3 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









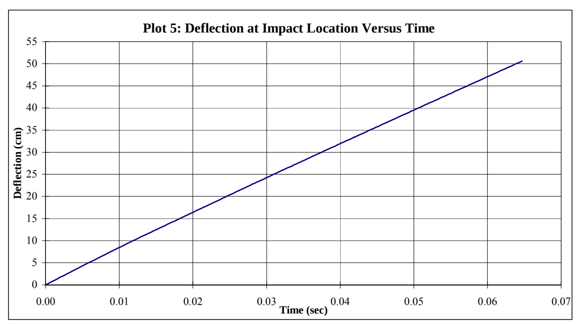
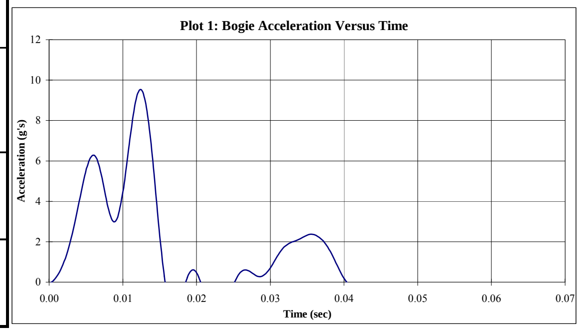
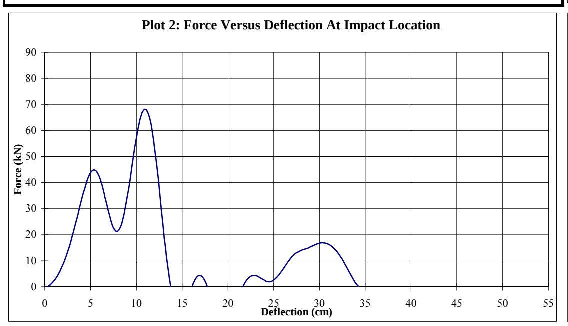


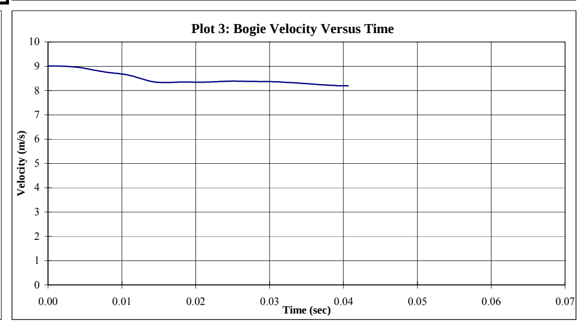
Figure 92. Results of Test No. DF-8

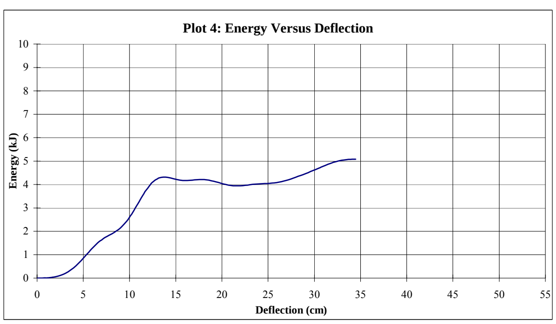
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-9		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia.	metric	7.22 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.2 mph)	(29.6 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









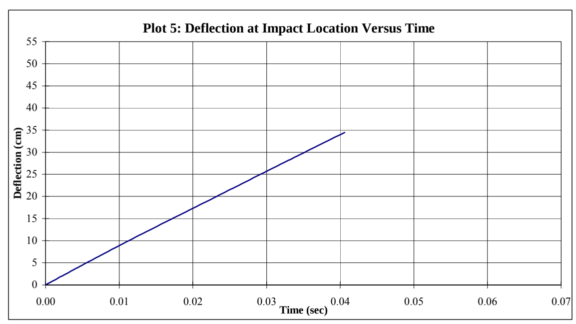
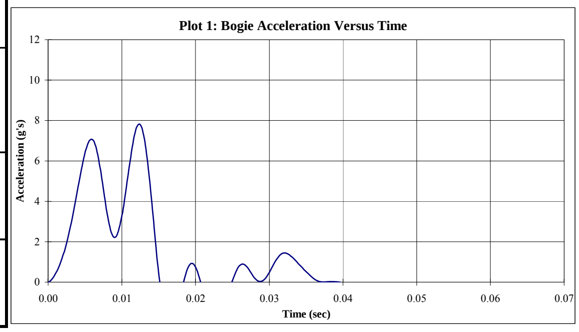


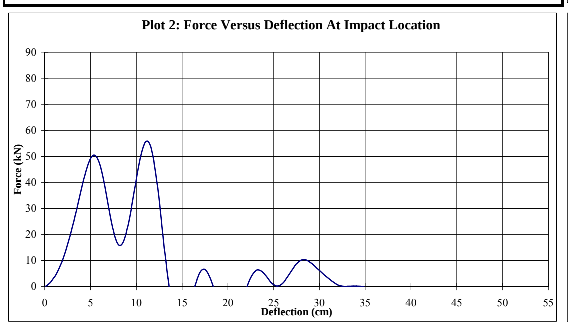
Figure 93. Results of Test No. DF-9

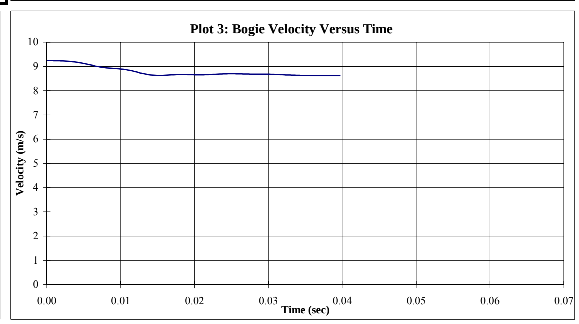
Midwest Roadside Safety Facility

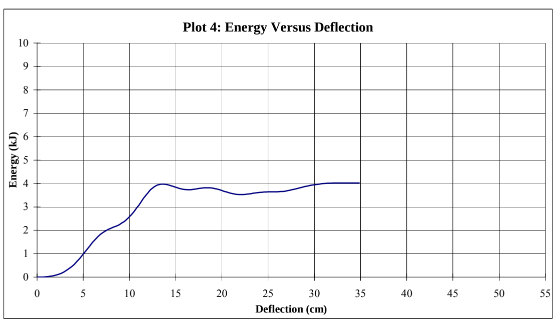
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-10		
Test Date:	9-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia.	metric	7.27 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	KNOTS		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.7 mph)	(30.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









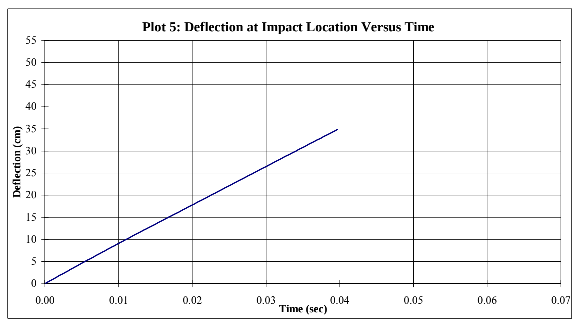
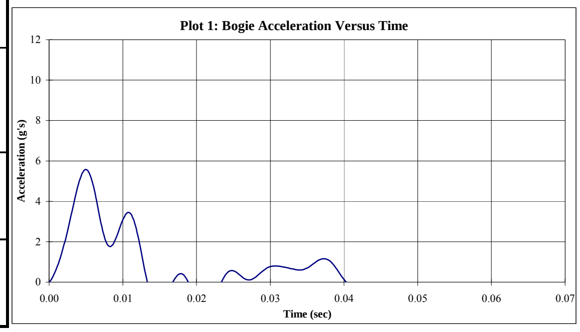


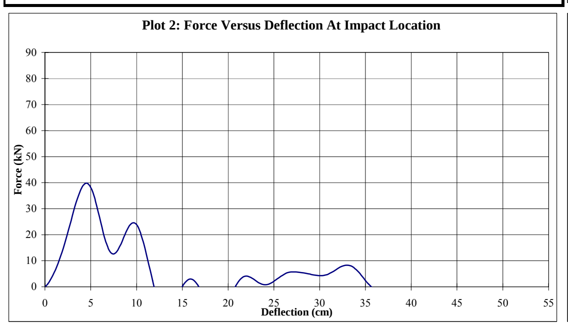
Figure 94. Results of Test No. DF-10

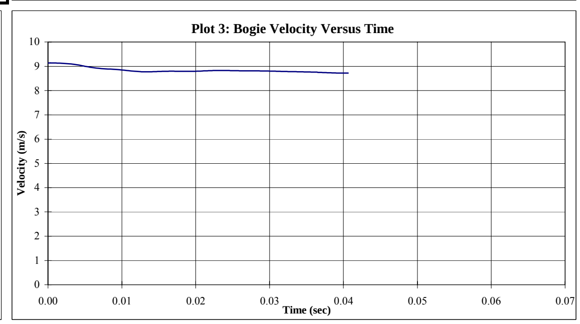
Midwest Roadside Safety Facility

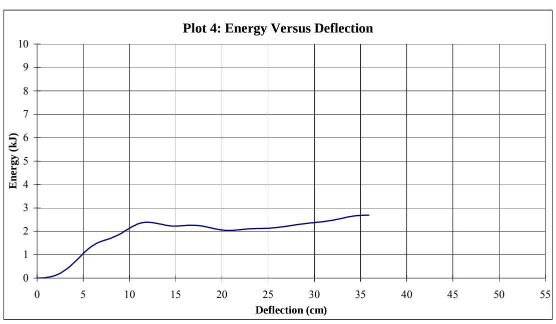
Bogie Test Summary

Test Information		CL Bogie MGS Height	
	Test Number:	DF-11	
	Test Date:	12-Nov-2004	
	Failure Type:	0	
Post Properties			
	Post Type:	Douglas Fir - Round Wooden	
	Post Size:	187.6 mm Dia. metric	7.39 in. Dia.
	Post Length:	197.9 cm	(502.6 cm)
	Embedment Depth:	101.6 cm	(258.1 cm)
	Category:	BASELINE	
Soil Properties			
	Gradation:		NA
	Moisture Content:		NA
	Compaction Method:		NA
	Soil Density, γ_d:	NA kg/m³	NA
Bogie Properties			
	Impact Velocity:	9.1 m/s	(20.4 mph) (30.0 fps)
	Impact Location:	63.2 cm	(24.9 in) above groundline
	Bogie Mass:	728 kg	(1605 lbf)
Data Acquired			
	Accelerometer Data:		EDR-3
	Camera Data:	Side View-DV and Photron	









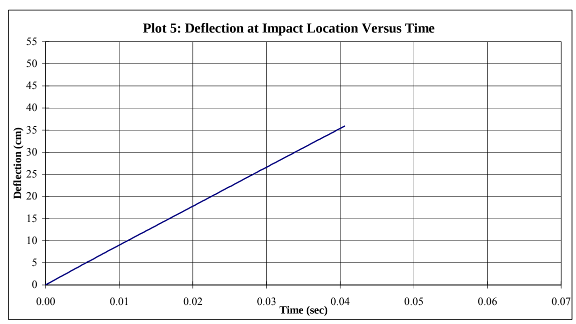
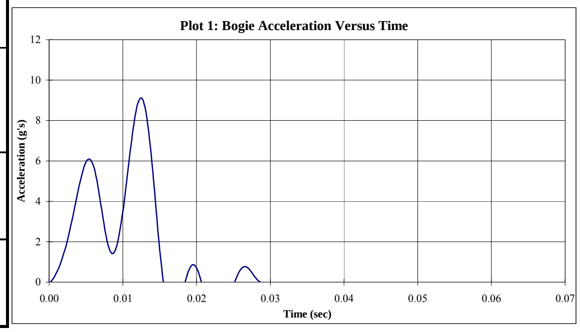
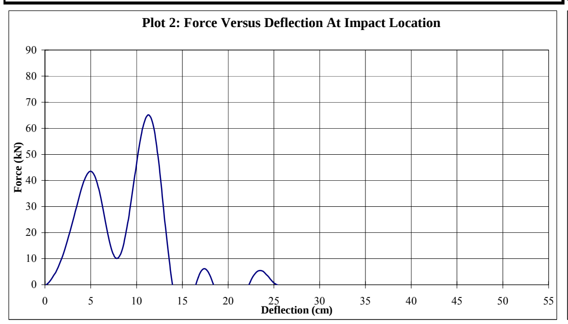


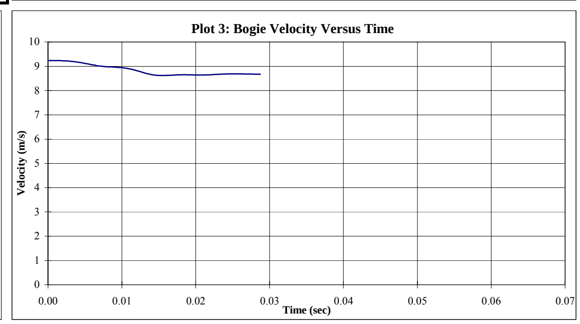
Figure 95. Results of Test No. DF-11

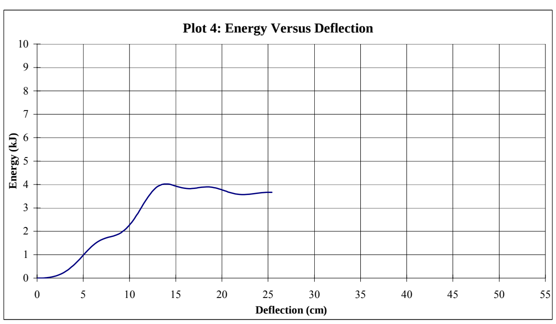
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	DF-12	
Test Date:	12-Nov-2004	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	182.2 mm Dia. metric	7.18 in. Dia.
Post Length:	196.7 cm	(499.6 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	BASELINE	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	9.2 m/s	(20.7 mph) (30.3 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









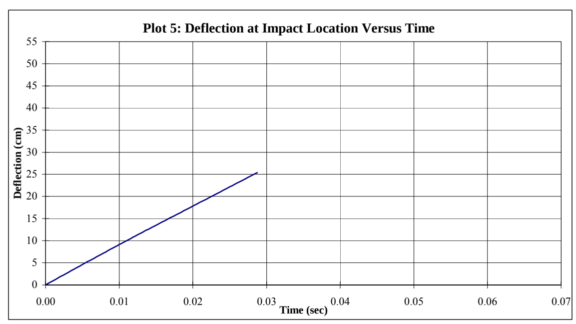
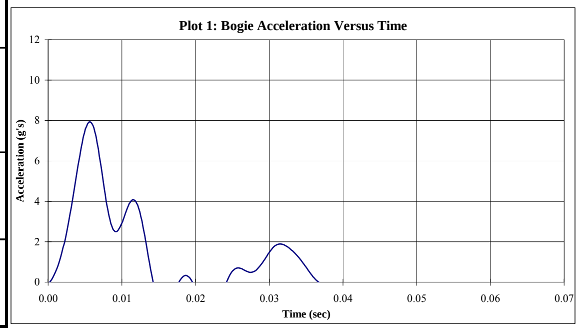
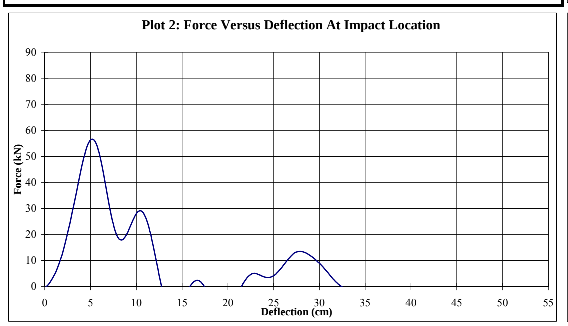


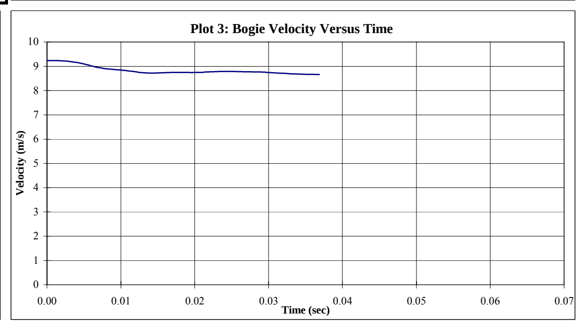
Figure 96. Results of Test No. DF-12

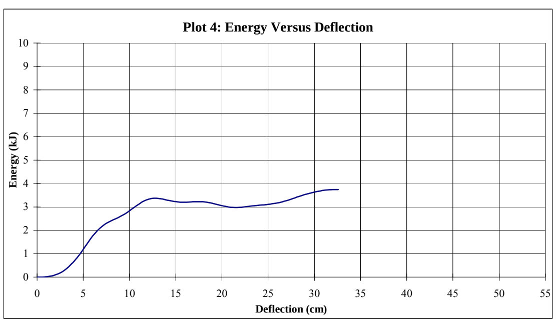
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-13		
Test Date:	12-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	190.8 mm Dia.	metric	7.51 in. Dia.
Post Length:	197.5 cm		(501.6 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	BASELINE		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.7 mph)	(30.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	Side View-DV and Photron		









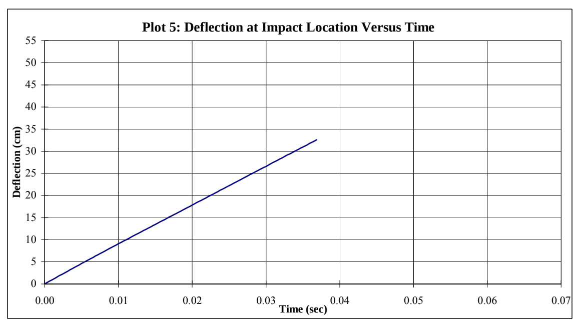
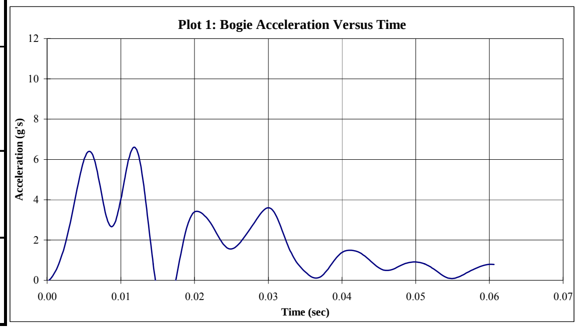


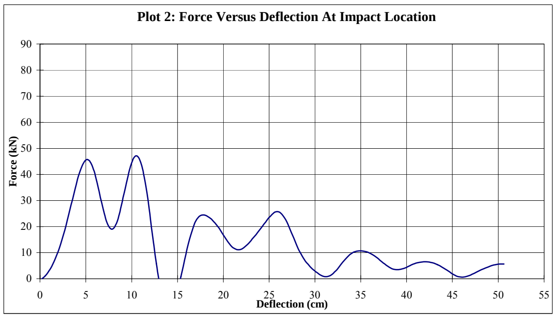
Figure 97. Results of Test No. DF-13

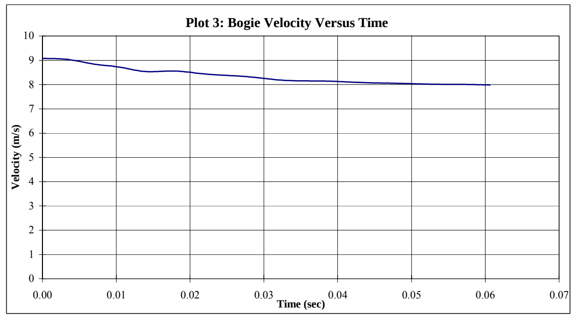
Midwest Roadside Safety Facility

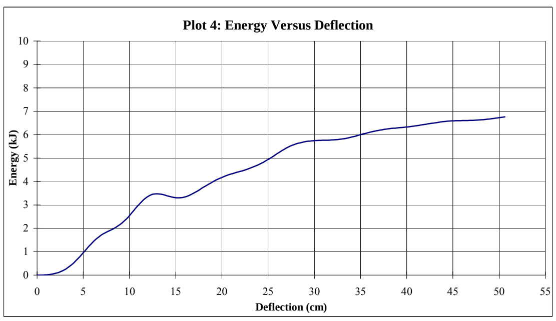
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	DF-14	
Test Date:	12-Nov-2004	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	185.95 mm Dia. metric	7.321 in. Dia.
Post Length:	196.5 cm	(499.2 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	BASELINE	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	9.1 m/s	(20.3 mph) (29.8 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV and Photron	









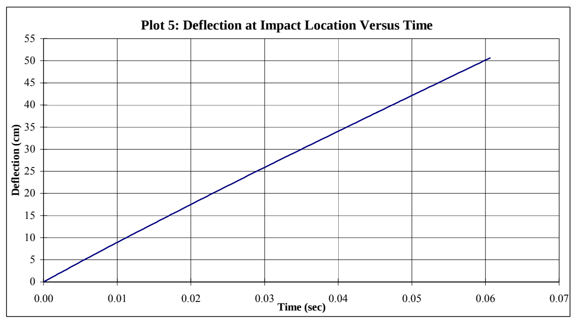
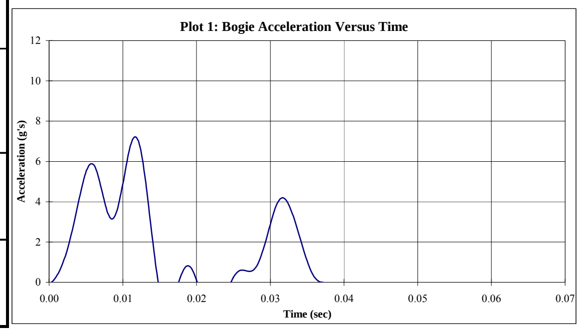


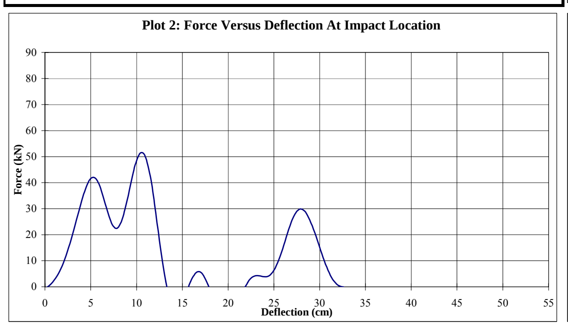
Figure 98. Results of Test No. DF-14

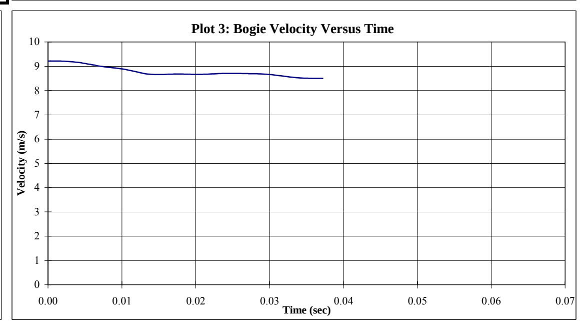
Midwest Roadside Safety Facility

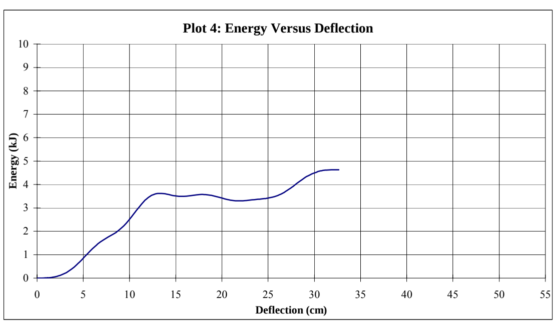
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-15		
Test Date:	12-Nov-2004		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	186.97 mm Dia. metric	7.361 in. Dia.	
Post Length:	196.9 cm	(500.0 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	BASELINE		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.6 mph)	(30.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV and Photron		









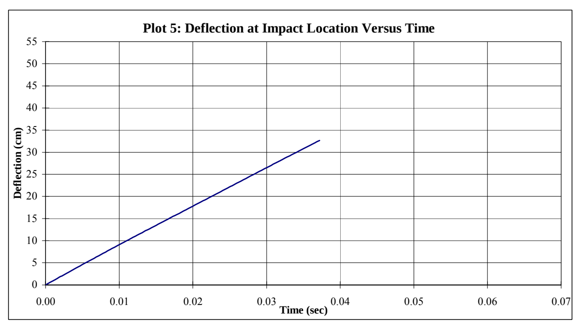
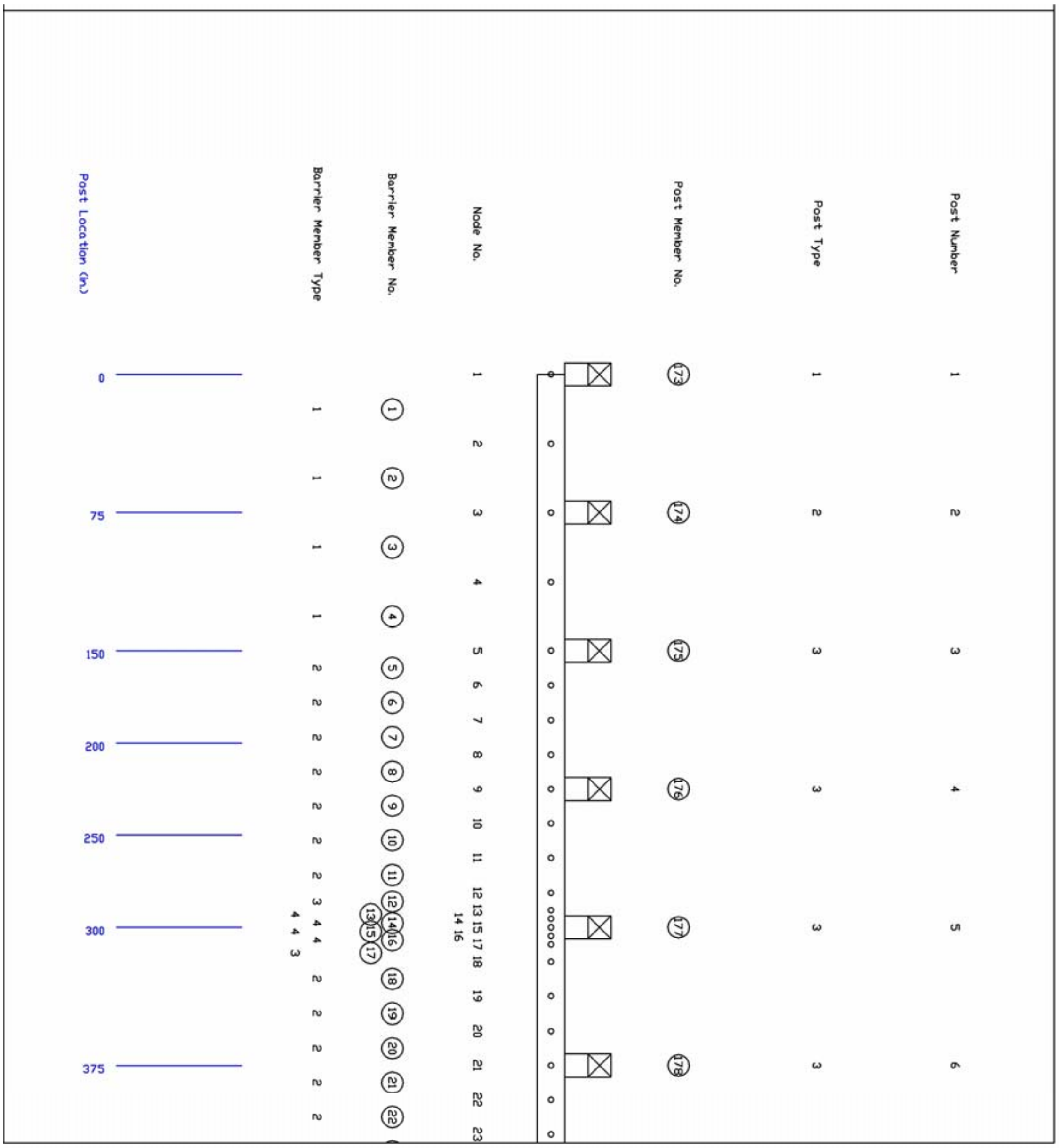
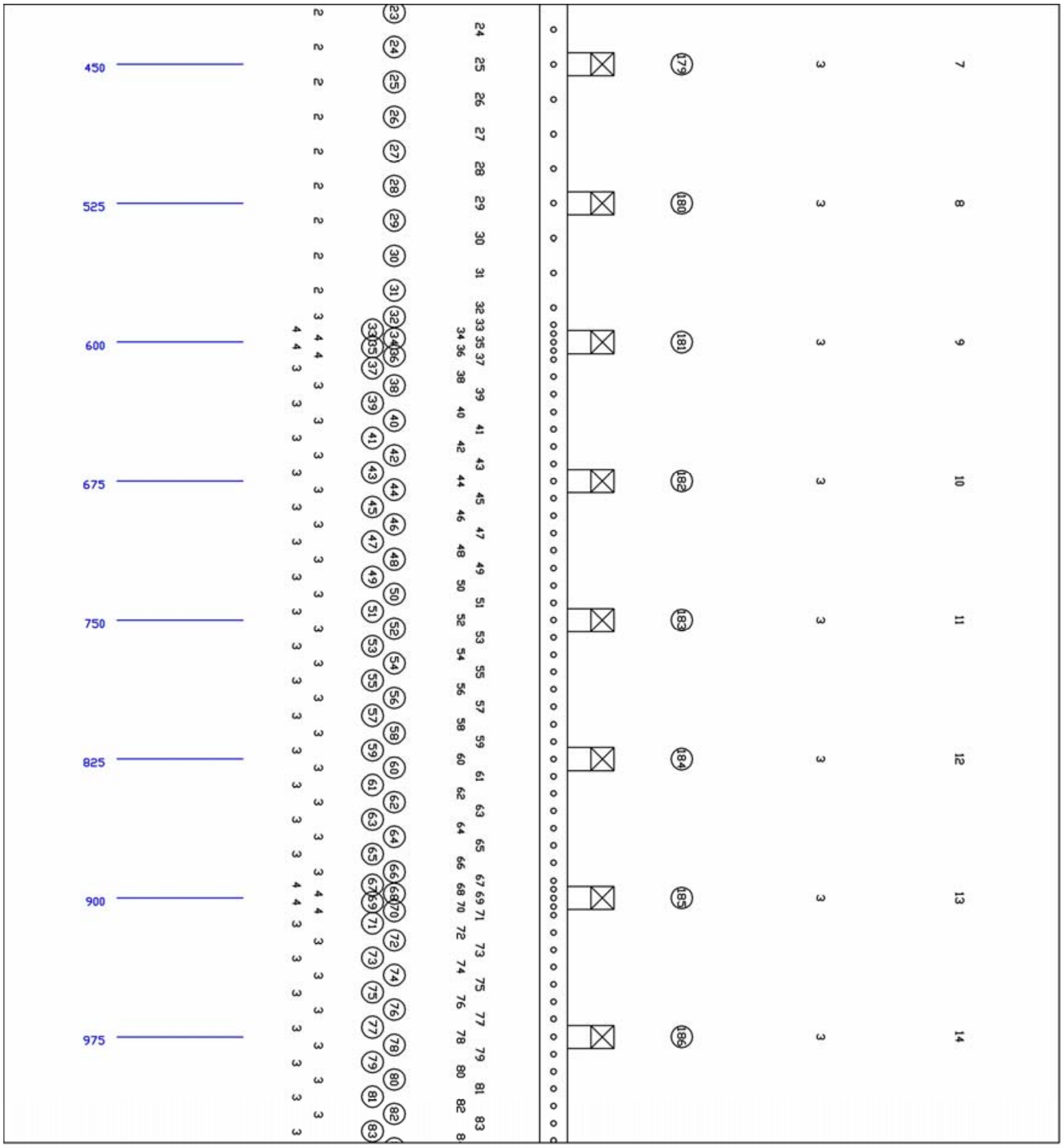


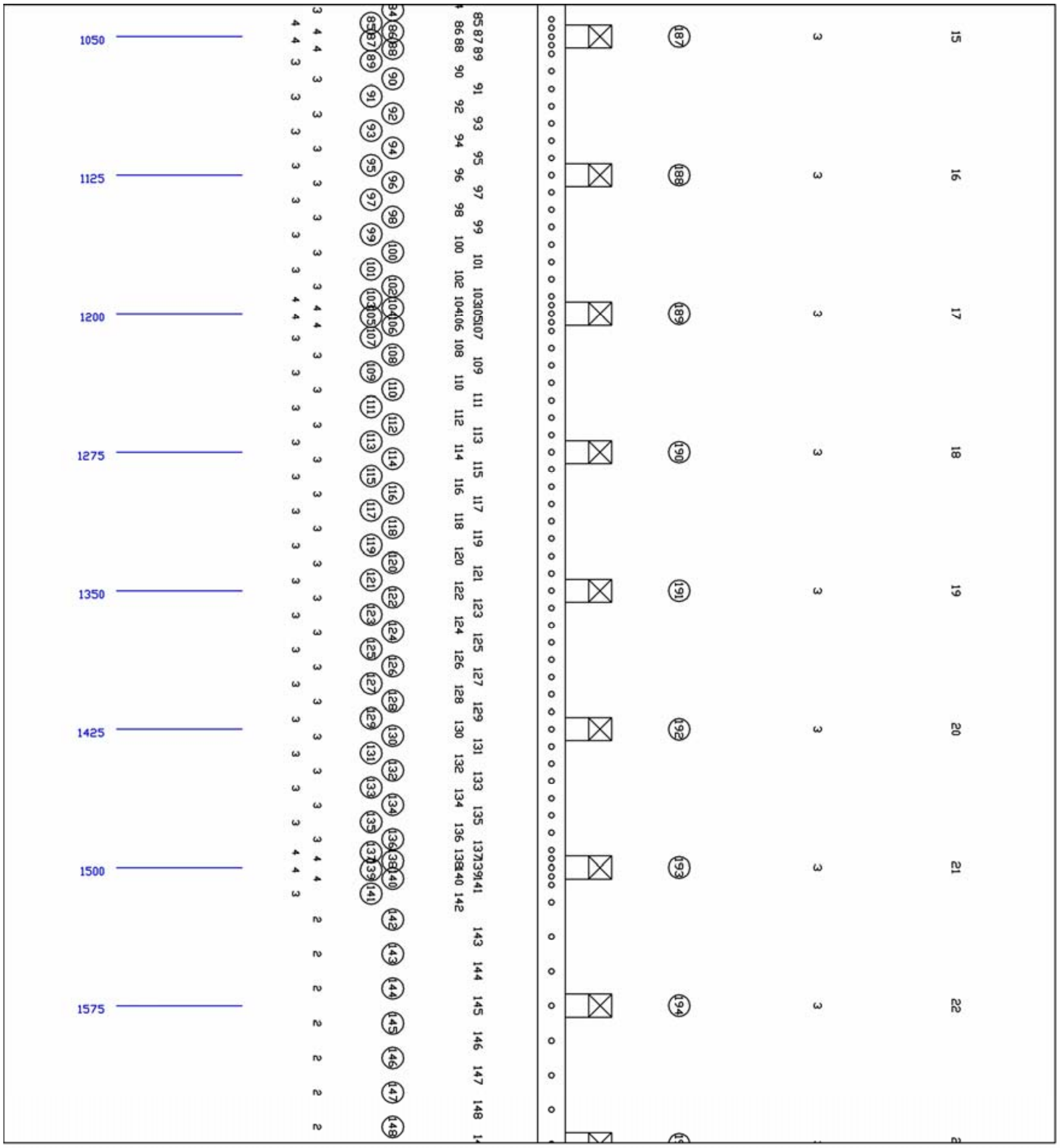
Figure 99. Results of Test No. DF-15

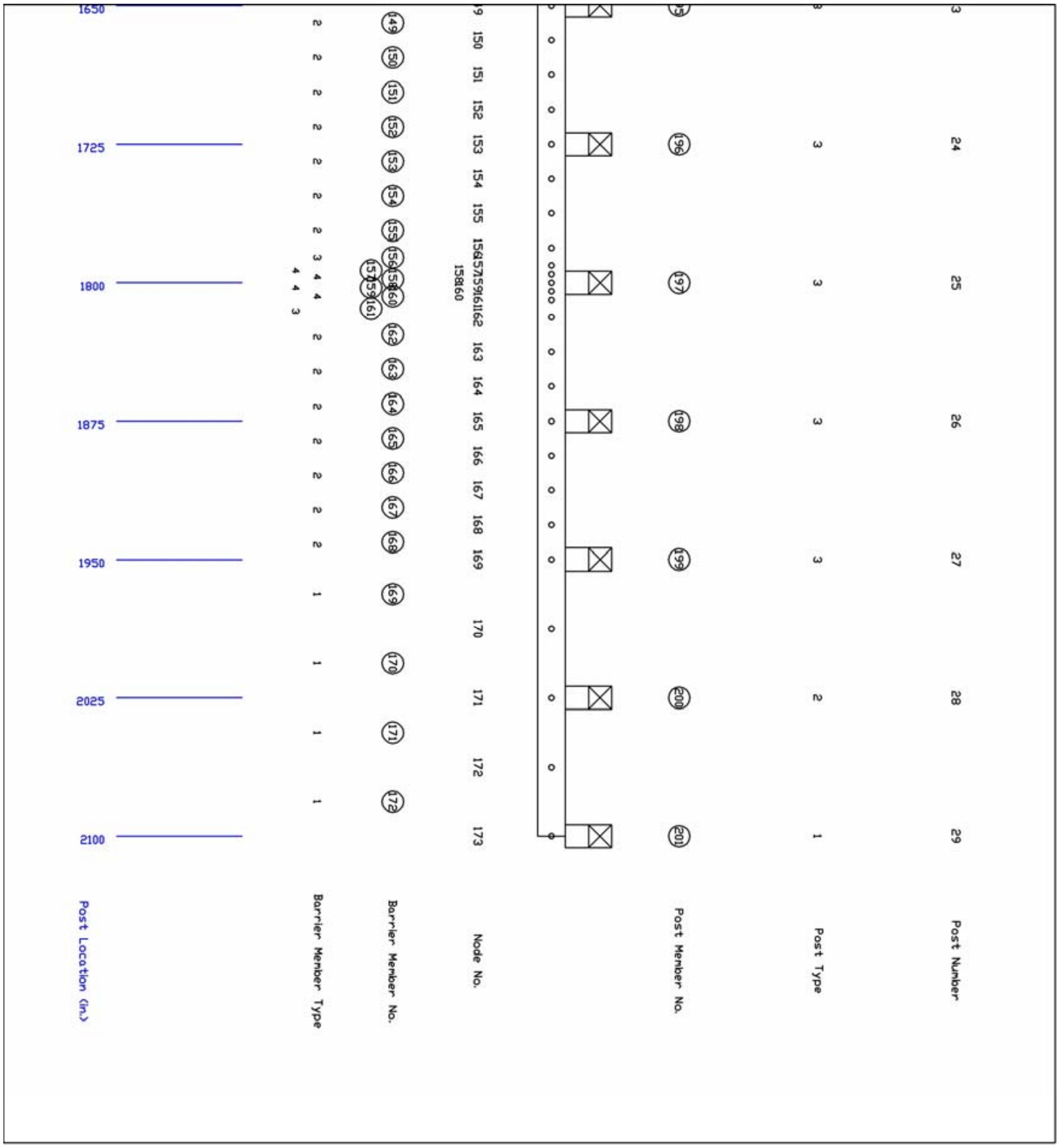
Appendix C. Barrier VII Simulation Deck

BARRIER VII – Model Schematic




450
525
600
675
750
825
900
975


1050
1125
1200
1275
1350
1425
1500
1575


Post Number
Post Type
Post Member No.
Node No.
Barrier Member No.
Barrier Member Type
Post Location (in.)
1650
1725
1800
1875
1950
2025
2100

BARRIER VII – Input Deck – Approximated Round Post

```
FPL-MGS Baseline Model With Approx. Round Posts FPL-B-1.b7
  173   71   28    1  201   73    2    0
    0.0001    0.0001      2.000 2000    0       1.0    1
    2   10   10   10   10  500    1
    1       0.0         0.0
    3     75.00         0.0
    5    150.00         0.0
    9    225.00         0.0
   12    281.25         0.0
   13   290.625         0.0
   14  295.3125         0.0
   15    300.00         0.0
   16  304.6875         0.0
   17   309.375         0.0
   18    318.75         0.0
   21    375.00         0.0
   25    450.00         0.0
   29    525.00         0.0
   32    581.25         0.0
   33   590.625         0.0
   34  595.3125         0.0
   35    600.00         0.0
   36  604.6875         0.0
   37   609.375         0.0
   38    618.75         0.0
   44    675.00         0.0
   52    750.00         0.0
   60    825.00         0.0
   66    881.25         0.0
   67   890.625         0.0
   68  895.3125         0.0
   69    900.00         0.0
   70  904.6875         0.0
   71   909.375         0.0
   72    918.75         0.0
   78    975.00         0.0
   84   1031.25         0.0
   85  1040.625         0.0
   86 1045.3125         0.0
   87   1050.00         0.0
   88 1054.6875         0.0
   89  1059.375         0.0
   90   1068.75         0.0
   96   1125.00         0.0
  102   1181.25         0.0
  103  1190.625         0.0
  104 1195.3125         0.0
  105   1200.00         0.0
  106 1204.6875         0.0
  107  1209.375         0.0
  108   1218.75         0.0
  114   1275.00         0.0
  122   1350.00         0.0
  130   1425.00         0.0
  136   1481.25         0.0
  137  1490.625         0.0
  138 1495.3125         0.0
  139   1500.00         0.0
  140 1504.6875         0.0
  141  1509.375         0.0
  142   1518.75         0.0
  145   1575.00         0.0
  149   1650.00         0.0
  153   1725.00         0.0
  156   1781.25         0.0
  157  1790.625         0.0
  158 1795.3125         0.0
  159   1800.00         0.0
```

```
  160 1804.6875       0.0
  161  1809.375       0.0
  162   1818.75       0.0
  165   1875.00       0.0
  169   1950.00       0.0
  171   2025.00       0.0
  173   2100.00       0.0
    1    3    1    1       0.0
    3    5    1    1       0.0
    5    9    3    1       0.0
    9   12    2    1       0.0
   18   21    2    1       0.0
   21   25    3    1       0.0
   25   29    3    1       0.0
   29   32    2    1       0.0
   38   44    5    1       0.0
   44   52    7    1       0.0
   52   60    7    1       0.0
   60   66    5    1       0.0
   72   78    5    1       0.0
   78   84    5    1       0.0
   90   96    5    1       0.0
   96  102    5    1       0.0
  108  114    5    1       0.0
  114  122    7    1       0.0
  122  130    7    1       0.0
  130  136    5    1       0.0
  142  145    2    1       0.0
  145  149    3    1       0.0
  149  153    3    1       0.0
  153  156    2    1       0.0
  162  165    2    1       0.0
  165  169    3    1       0.0
  169  171    1    1       0.0
  171  173    1    1       0.0
    1  173      0.40
  173  172  171  170  169  168  167  166  165  164
  163  162  161  160  159  158  157  156  155  154
  153  152  151  150  149  148  147  146  145  144
  143  142  141  140  139  138  137  136  135  134
  133  132  131  130  129  128  127  126  125  124
  123  122  121  120  119  118  117  116  115  114
  113  112  111  110  109  108  107  106  105  104
  103  102  101  100   99   98   97   96   95   94
   93   92   91   90   89   88   87   86   85   84
   83   82   81   80   79   78   77   76   75   74
   73   72   71   70   69   68   67   66   65   64
   63   62   61   60   59   58   57   56   55   54
   53   52   51   50   49   48   47   46   45   44
   43   42   41   40   39   38   37   36   35   34
   33   32   31   30   29   28   27   26   25   24
   23   22   21   20   19   18   17   16   15   14
   13   12   11   10    9    8    7    6    5    4
    3    2    1
  100    4
    1      2.29      1.99     37.50   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
    2      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
    3      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
    4      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
  300    4
    1    24.875      0.00       6.0       6.0     100.0     675.0     675.0 0.05
Simulated Strong Anchor Post
     100.0     100.0      15.0      15.0
    2    24.875      0.00       3.0       3.0     100.0     150.0    225.00 0.05
Second BCT Post
      50.0      50.0      15.0      15.0
    3    24.875       0.0      1.34      6.75      60.0     92.88    143.65 0.05
FPL Strong Round Post Overall
```

```
      15.0       15.0       15.0       15.0
    4    24.875       0.0      1.34       6.75      60.0      92.88     143.65 0.05
FPL Weak Round Post Overall
       7.0        7.0        2.4        2.4
    1     1     2     4     1  101        0.0        0.0        0.0
    5     5     6    11     1  102        0.0        0.0        0.0
   12    12    13              103        0.0        0.0        0.0
   13    13    14              104        0.0        0.0        0.0
   14    14    15              104        0.0        0.0        0.0
   15    15    16              104        0.0        0.0        0.0
   16    16    17              104        0.0        0.0        0.0
   17    17    18              103        0.0        0.0        0.0
   18    18    19    31     1  102        0.0        0.0        0.0
   32    32    33              103        0.0        0.0        0.0
   33    33    34              104        0.0        0.0        0.0
   34    34    35              104        0.0        0.0        0.0
   35    35    36              104        0.0        0.0        0.0
   36    36    37              104        0.0        0.0        0.0
   37    37    38    66     1  103        0.0        0.0        0.0
   67    67    68              104        0.0        0.0        0.0
   68    68    69              104        0.0        0.0        0.0
   69    69    70              104        0.0        0.0        0.0
   70    70    71              104        0.0        0.0        0.0
   71    71    72    84     1  103        0.0        0.0        0.0
   85    85    86              104        0.0        0.0        0.0
   86    86    87              104        0.0        0.0        0.0
   87    87    88              104        0.0        0.0        0.0
   88    88    89              104        0.0        0.0        0.0
   89    89    90   102     1  103        0.0        0.0        0.0
  103   103   104              104        0.0        0.0        0.0
  104   104   105              104        0.0        0.0        0.0
  105   105   106              104        0.0        0.0        0.0
  106   106   107              104        0.0        0.0        0.0
  107   107   108   136     1  103        0.0        0.0        0.0
  137   137   138              104        0.0        0.0        0.0
  138   138   139              104        0.0        0.0        0.0
  139   139   140              104        0.0        0.0        0.0
  140   140   141              104        0.0        0.0        0.0
  141   141   142              103        0.0        0.0        0.0
  142   142   143   155     1  102        0.0        0.0        0.0
  156   156   157              103        0.0        0.0        0.0
  157   157   158              104        0.0        0.0        0.0
  158   158   159              104        0.0        0.0        0.0
  159   159   160              104        0.0        0.0        0.0
  160   160   161              104        0.0        0.0        0.0
  161   161   162              103        0.0        0.0        0.0
  162   162   163   168     1  102        0.0        0.0        0.0
  169   169   170   172     1  101        0.0        0.0        0.0
  173     1                    301        0.0        0.0        0.0        0.0        0.0
  174     3                    302        0.0        0.0        0.0        0.0        0.0
  175     5                    303        0.0        0.0        0.0        0.0        0.0
  176     9                    303        0.0        0.0        0.0        0.0        0.0
  177    15                    303        0.0        0.0        0.0        0.0        0.0
  178    21                    303        0.0        0.0        0.0        0.0        0.0
  179    25                    303        0.0        0.0        0.0        0.0        0.0
  180    29                    303        0.0        0.0        0.0        0.0        0.0
  181    35                    303        0.0        0.0        0.0        0.0        0.0
  182    44                    303        0.0        0.0        0.0        0.0        0.0
  183    52                    303        0.0        0.0        0.0        0.0        0.0
  184    60                    303        0.0        0.0        0.0        0.0        0.0
  185    69                    303        0.0        0.0        0.0        0.0        0.0
  186    78                    303        0.0        0.0        0.0        0.0        0.0
  187    87                    303        0.0        0.0        0.0        0.0        0.0
  188    96                    303        0.0        0.0        0.0        0.0        0.0
  189   105                    303        0.0        0.0        0.0        0.0        0.0
  190   114                    303        0.0        0.0        0.0        0.0        0.0
  191   122                    303        0.0        0.0        0.0        0.0        0.0
  192   130                    303        0.0        0.0        0.0        0.0        0.0
  193   139                    303        0.0        0.0        0.0        0.0        0.0
  194   145                    303        0.0        0.0        0.0        0.0        0.0
  195   149                    303        0.0        0.0        0.0        0.0        0.0
  196   153                    303        0.0        0.0        0.0        0.0        0.0
```

```
197  159                303       0.0       0.0       0.0       0.0       0.0
198  165                303       0.0       0.0       0.0       0.0       0.0
199  169                303       0.0       0.0       0.0       0.0       0.0
200  171                302       0.0       0.0       0.0       0.0       0.0
201  173                301       0.0       0.0       0.0       0.0       0.0
  4400.0   47400.0   20    6    4    0   25
  1     0.055      0.12     6.00      17.0
  2     0.057      0.15     7.00      18.0
  3     0.062      0.18    10.00      12.0
  4     0.110      0.35    12.00       6.0
  5      0.35      0.45     6.00       5.0
  6      1.45      1.50    15.00       1.0
  1    100.75    15.875    1      12.0    1    1    0    0
  2    100.75    27.875    1      12.0    1    1    0    0
  3    100.75    39.875    2      12.0    1    1    0    0
  4     88.75    39.875    2      12.0    1    1    0    0
  5     76.75    39.875    2      12.0    1    1    0    0
  6     64.75    39.875    2      12.0    1    1    0    0
  7     52.75    39.875    2      12.0    1    1    0    0
  8     40.75    39.875    2      12.0    1    1    0    0
  9     28.75    39.875    2      12.0    1    1    0    0
 10     16.75    39.875    2      12.0    1    1    0    0
 11    -13.25    39.875    3      12.0    1    1    0    0
 12    -33.25    39.875    3      12.0    1    1    0    0
 13    -53.25    39.875    3      12.0    1    1    0    0
 14    -73.25    39.875    3      12.0    1    1    0    0
 15    -93.25    39.875    3      12.0    1    1    0    0
 16   -113.25    39.875    4      12.0    1    1    0    0
 17   -113.25   -39.875    4      12.0    0    0    0    0
 18    100.75   -39.875    1      12.0    0    0    0    0
 19     69.25     37.75    5       1.0    1    1    0    0
 20    -62.75     37.75    6       1.0    1    1    0    0
  1     69.25     32.75       0.0      608.
  2     69.25    -32.75       0.0      608.
  3    -62.75     32.75       0.0      492.
  4    -62.75    -32.75       0.0      492.
  1    100.75     39.88
  2   -113.25     39.88
  3   -113.25    -39.88
  4    100.75    -39.88
  5      5.00      2.50
  6      5.00     -2.50
  7     -5.00     -2.50
  8     -5.00      2.50
  9     83.75     37.75
 10     83.75     27.75
 11     54.75     27.75
 12     54.75     37.75
 13     83.75    -27.75
 14     83.75    -37.75
 15     54.75    -37.75
 16     54.75    -27.75
 17    -48.25     37.75
 18    -48.25     27.75
 19    -77.25     27.75
 20    -77.25     37.75
 21    -48.25    -27.75
 22    -48.25    -37.75
 23    -77.25    -37.75
 24    -77.25    -27.75
 25      0.00      0.00
  3    787.50       0.0      25.0     62.14       0.0       0.0       1.0
```

BARRIER VII – Input Deck – Average Round Post

```
FPL-MGS Baseline Model With Overall Approx. Round Posts FPL-B-1.b7
  173   71   28    1  201   73    2    0
    0.0001    0.0001      2.000 2000    0       1.0    1
    2   10   10   10   10  500    1
    1       0.0       0.0
    3     75.00       0.0
    5    150.00       0.0
    9    225.00       0.0
   12    281.25       0.0
   13   290.625       0.0
   14  295.3125       0.0
   15    300.00       0.0
   16  304.6875       0.0
   17   309.375       0.0
   18    318.75       0.0
   21    375.00       0.0
   25    450.00       0.0
   29    525.00       0.0
   32    581.25       0.0
   33   590.625       0.0
   34  595.3125       0.0
   35    600.00       0.0
   36  604.6875       0.0
   37   609.375       0.0
   38    618.75       0.0
   44    675.00       0.0
   52    750.00       0.0
   60    825.00       0.0
   66    881.25       0.0
   67   890.625       0.0
   68  895.3125       0.0
   69    900.00       0.0
   70  904.6875       0.0
   71   909.375       0.0
   72    918.75       0.0
   78    975.00       0.0
   84   1031.25       0.0
   85  1040.625       0.0
   86 1045.3125       0.0
   87   1050.00       0.0
   88 1054.6875       0.0
   89  1059.375       0.0
   90   1068.75       0.0
   96   1125.00       0.0
  102   1181.25       0.0
  103  1190.625       0.0
  104 1195.3125       0.0
  105   1200.00       0.0
  106 1204.6875       0.0
  107  1209.375       0.0
  108   1218.75       0.0
  114   1275.00       0.0
  122   1350.00       0.0
  130   1425.00       0.0
  136   1481.25       0.0
  137  1490.625       0.0
  138 1495.3125       0.0
  139   1500.00       0.0
  140 1504.6875       0.0
  141  1509.375       0.0
  142   1518.75       0.0
  145   1575.00       0.0
  149   1650.00       0.0
  153   1725.00       0.0
  156   1781.25       0.0
  157  1790.625       0.0
  158 1795.3125       0.0
  159   1800.00       0.0
```

```
  160 1804.6875       0.0
  161  1809.375       0.0
  162   1818.75       0.0
  165   1875.00       0.0
  169   1950.00       0.0
  171   2025.00       0.0
  173   2100.00       0.0
    1    3    1    1       0.0
    3    5    1    1       0.0
    5    9    3    1       0.0
    9   12    2    1       0.0
   18   21    2    1       0.0
   21   25    3    1       0.0
   25   29    3    1       0.0
   29   32    2    1       0.0
   38   44    5    1       0.0
   44   52    7    1       0.0
   52   60    7    1       0.0
   60   66    5    1       0.0
   72   78    5    1       0.0
   78   84    5    1       0.0
   90   96    5    1       0.0
   96  102    5    1       0.0
  108  114    5    1       0.0
  114  122    7    1       0.0
  122  130    7    1       0.0
  130  136    5    1       0.0
  142  145    2    1       0.0
  145  149    3    1       0.0
  149  153    3    1       0.0
  153  156    2    1       0.0
  162  165    2    1       0.0
  165  169    3    1       0.0
  169  171    1    1       0.0
  171  173    1    1       0.0
    1  173      0.40
  173  172  171  170  169  168  167  166  165  164
  163  162  161  160  159  158  157  156  155  154
  153  152  151  150  149  148  147  146  145  144
  143  142  141  140  139  138  137  136  135  134
  133  132  131  130  129  128  127  126  125  124
  123  122  121  120  119  118  117  116  115  114
  113  112  111  110  109  108  107  106  105  104
  103  102  101  100   99   98   97   96   95   94
   93   92   91   90   89   88   87   86   85   84
   83   82   81   80   79   78   77   76   75   74
   73   72   71   70   69   68   67   66   65   64
   63   62   61   60   59   58   57   56   55   54
   53   52   51   50   49   48   47   46   45   44
   43   42   41   40   39   38   37   36   35   34
   33   32   31   30   29   28   27   26   25   24
   23   22   21   20   19   18   17   16   15   14
   13   12   11   10    9    8    7    6    5    4
    3    2    1
  100    4
    1      2.29      1.99     37.50   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
    2      2.29      1.99     18.75   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
    3      2.29      1.99     9.375   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
    4      2.29      1.99    4.6875   30000.0      6.92      99.5      68.5 0.05
12-Gauge W-Beam
  300    4
    1    24.875      0.00       6.0       6.0     100.0     675.0     675.0 0.05
Simulated Strong Anchor Post
     100.0     100.0      15.0      15.0
    2    24.875      0.00       3.0       3.0     100.0     150.0    225.00 0.05
Second BCT Post
      50.0      50.0      15.0      15.0
    3    24.875       0.0      1.34      6.75      60.0     92.00    161.50 0.05
FPL Strong Round Post Overall
```

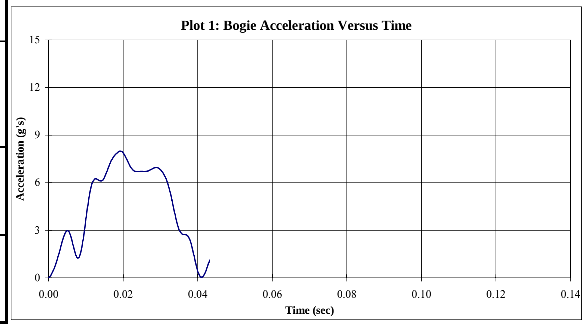
```
      15.0      15.0      15.0      15.0
    4   24.875       0.0      1.34      6.75      60.0     92.00    161.50 0.05
FPL Weak Round Post Overall
       7.0       7.0       2.4       2.4
    1    1    2    4    1  101       0.0       0.0       0.0
    5    5    6   11    1  102       0.0       0.0       0.0
   12   12   13            103       0.0       0.0       0.0
   13   13   14            104       0.0       0.0       0.0
   14   14   15            104       0.0       0.0       0.0
   15   15   16            104       0.0       0.0       0.0
   16   16   17            104       0.0       0.0       0.0
   17   17   18            103       0.0       0.0       0.0
   18   18   19   31    1  102       0.0       0.0       0.0
   32   32   33            103       0.0       0.0       0.0
   33   33   34            104       0.0       0.0       0.0
   34   34   35            104       0.0       0.0       0.0
   35   35   36            104       0.0       0.0       0.0
   36   36   37            104       0.0       0.0       0.0
   37   37   38   66    1  103       0.0       0.0       0.0
   67   67   68            104       0.0       0.0       0.0
   68   68   69            104       0.0       0.0       0.0
   69   69   70            104       0.0       0.0       0.0
   70   70   71            104       0.0       0.0       0.0
   71   71   72   84    1  103       0.0       0.0       0.0
   85   85   86            104       0.0       0.0       0.0
   86   86   87            104       0.0       0.0       0.0
   87   87   88            104       0.0       0.0       0.0
   88   88   89            104       0.0       0.0       0.0
   89   89   90  102    1  103       0.0       0.0       0.0
  103  103  104            104       0.0       0.0       0.0
  104  104  105            104       0.0       0.0       0.0
  105  105  106            104       0.0       0.0       0.0
  106  106  107            104       0.0       0.0       0.0
  107  107  108  136    1  103       0.0       0.0       0.0
  137  137  138            104       0.0       0.0       0.0
  138  138  139            104       0.0       0.0       0.0
  139  139  140            104       0.0       0.0       0.0
  140  140  141            104       0.0       0.0       0.0
  141  141  142            103       0.0       0.0       0.0
  142  142  143  155    1  102       0.0       0.0       0.0
  156  156  157            103       0.0       0.0       0.0
  157  157  158            104       0.0       0.0       0.0
  158  158  159            104       0.0       0.0       0.0
  159  159  160            104       0.0       0.0       0.0
  160  160  161            104       0.0       0.0       0.0
  161  161  162            103       0.0       0.0       0.0
  162  162  163  168    1  102       0.0       0.0       0.0
  169  169  170  172    1  101       0.0       0.0       0.0
  173    1                 301       0.0       0.0       0.0       0.0       0.0
  174    3                 302       0.0       0.0       0.0       0.0       0.0
  175    5                 303       0.0       0.0       0.0       0.0       0.0
  176    9                 303       0.0       0.0       0.0       0.0       0.0
  177   15                 303       0.0       0.0       0.0       0.0       0.0
  178   21                 303       0.0       0.0       0.0       0.0       0.0
  179   25                 303       0.0       0.0       0.0       0.0       0.0
  180   29                 303       0.0       0.0       0.0       0.0       0.0
  181   35                 303       0.0       0.0       0.0       0.0       0.0
  182   44                 303       0.0       0.0       0.0       0.0       0.0
  183   52                 303       0.0       0.0       0.0       0.0       0.0
  184   60                 303       0.0       0.0       0.0       0.0       0.0
  185   69                 303       0.0       0.0       0.0       0.0       0.0
  186   78                 303       0.0       0.0       0.0       0.0       0.0
  187   87                 303       0.0       0.0       0.0       0.0       0.0
  188   96                 303       0.0       0.0       0.0       0.0       0.0
  189  105                 303       0.0       0.0       0.0       0.0       0.0
  190  114                 303       0.0       0.0       0.0       0.0       0.0
  191  122                 303       0.0       0.0       0.0       0.0       0.0
  192  130                 303       0.0       0.0       0.0       0.0       0.0
  193  139                 303       0.0       0.0       0.0       0.0       0.0
  194  145                 303       0.0       0.0       0.0       0.0       0.0
  195  149                 303       0.0       0.0       0.0       0.0       0.0
  196  153                 303       0.0       0.0       0.0       0.0       0.0
```

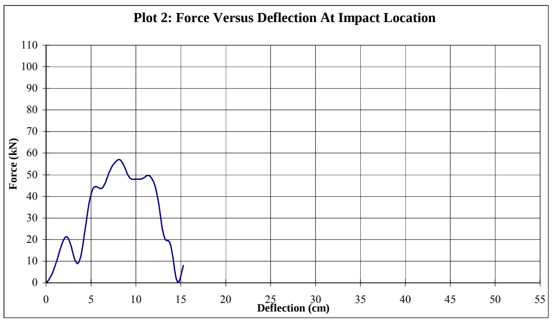
```
197  159                303       0.0       0.0       0.0       0.0       0.0
198  165                303       0.0       0.0       0.0       0.0       0.0
199  169                303       0.0       0.0       0.0       0.0       0.0
200  171                302       0.0       0.0       0.0       0.0       0.0
201  173                301       0.0       0.0       0.0       0.0       0.0
  4400.0   47400.0   20    6    4    0   25
  1     0.055      0.12     6.00      17.0
  2     0.057      0.15     7.00      18.0
  3     0.062      0.18    10.00      12.0
  4     0.110      0.35    12.00       6.0
  5      0.35      0.45     6.00       5.0
  6      1.45      1.50    15.00       1.0
  1    100.75    15.875    1      12.0    1    1    0    0
  2    100.75    27.875    1      12.0    1    1    0    0
  3    100.75    39.875    2      12.0    1    1    0    0
  4     88.75    39.875    2      12.0    1    1    0    0
  5     76.75    39.875    2      12.0    1    1    0    0
  6     64.75    39.875    2      12.0    1    1    0    0
  7     52.75    39.875    2      12.0    1    1    0    0
  8     40.75    39.875    2      12.0    1    1    0    0
  9     28.75    39.875    2      12.0    1    1    0    0
 10     16.75    39.875    2      12.0    1    1    0    0
 11    -13.25    39.875    3      12.0    1    1    0    0
 12    -33.25    39.875    3      12.0    1    1    0    0
 13    -53.25    39.875    3      12.0    1    1    0    0
 14    -73.25    39.875    3      12.0    1    1    0    0
 15    -93.25    39.875    3      12.0    1    1    0    0
 16   -113.25    39.875    4      12.0    1    1    0    0
 17   -113.25   -39.875    4      12.0    0    0    0    0
 18    100.75   -39.875    1      12.0    0    0    0    0
 19     69.25     37.75    5       1.0    1    1    0    0
 20    -62.75     37.75    6       1.0    1    1    0    0
  1     69.25     32.75      0.0      608.
  2     69.25    -32.75      0.0      608.
  3    -62.75     32.75      0.0      492.
  4    -62.75    -32.75      0.0      492.
  1    100.75     39.88
  2   -113.25     39.88
  3   -113.25    -39.88
  4    100.75    -39.88
  5      5.00      2.50
  6      5.00     -2.50
  7     -5.00     -2.50
  8     -5.00      2.50
  9     83.75     37.75
 10     83.75     27.75
 11     54.75     27.75
 12     54.75     37.75
 13     83.75    -27.75
 14     83.75    -37.75
 15     54.75    -37.75
 16     54.75    -27.75
 17    -48.25     37.75
 18    -48.25     27.75
 19    -77.25     27.75
 20    -77.25     37.75
 21    -48.25    -27.75
 22    -48.25    -37.75
 23    -77.25    -37.75
 24    -77.25    -27.75
 25      0.00      0.00
  3    787.50       0.0     25.0     62.14       0.0       0.0       1.0
```

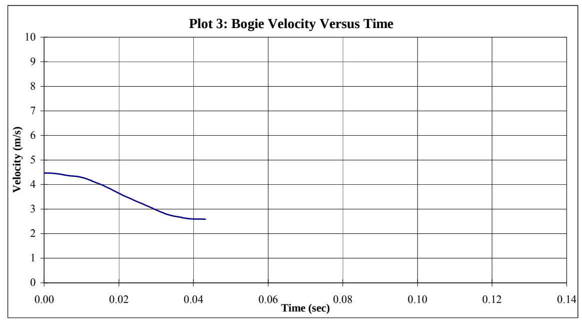
Appendix D. Supplemental Inertia Cantilever Bogie Test Results

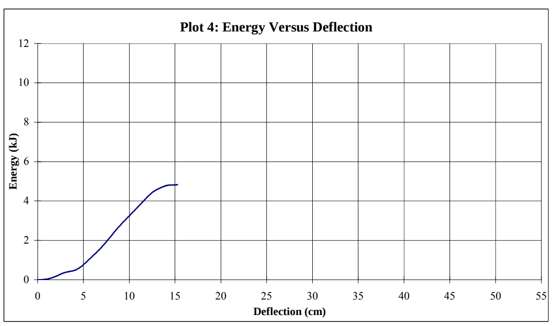
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	0 degrees		
Test Number:	SYPI - 1		
Test Date:	7-Jun-2005		
Failure Type:			
	0		
Post Properties			
Post Type:	ıthern Yellow Pine		
Post Size:	8.415 cm diameter metric		7.25" diameter
Post Length:		188.0 cm	(74.0 in)
Embedment Depth:		99.1 cm	(39.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:		NA kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:		4.5 m/s	(10.0 mph) (14.7 fps)
Impact Location:		55.0 cm	(21.7 in) above groundline
Bogie Mass:		728 kg	(1605 lbf)
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









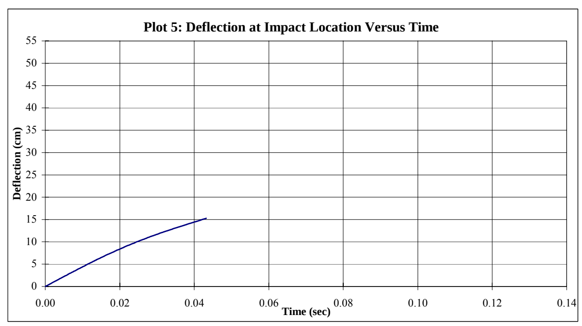
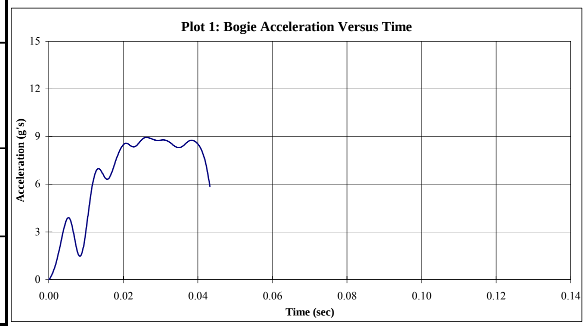


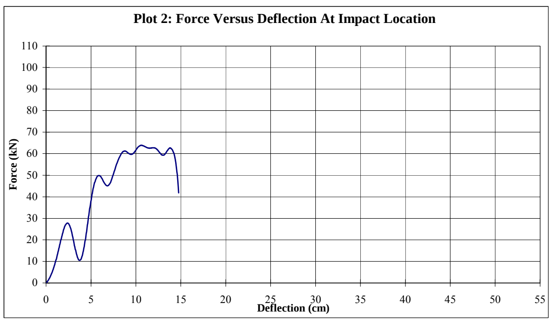
Figure 100. Results of Test No. SYPI-1

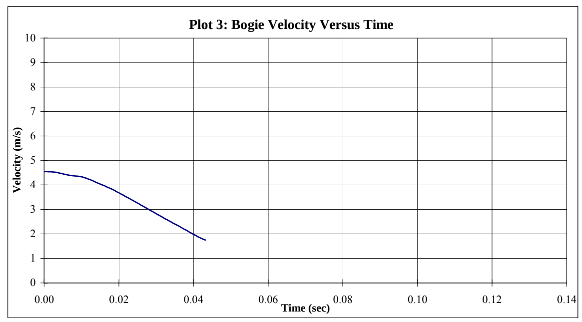
Midwest Roadside Safety Facility

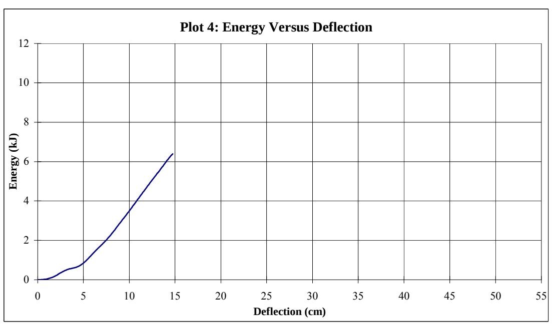
Bogie Test Summary

Test Information	0 degrees		
Test Number:	SYPI - 2		
Test Date:	7-Jun-2005		
Failure Type:			
	0		
Post Properties			
Post Type:	ıthern Yellow Pine		
Post Size:	8.415 cm diameter metric		7.25" diameter
Post Length:	198.1	cm	(78.0 in)
Embedment Depth:	99.1	cm	(39.0 in)
Soil Properties			
Gradation:		Steel Sleeve	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	4.5 m/s	(10.2 mph)	(14.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:		Side View-Digital	









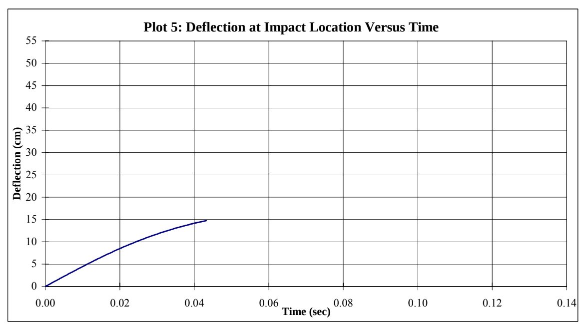
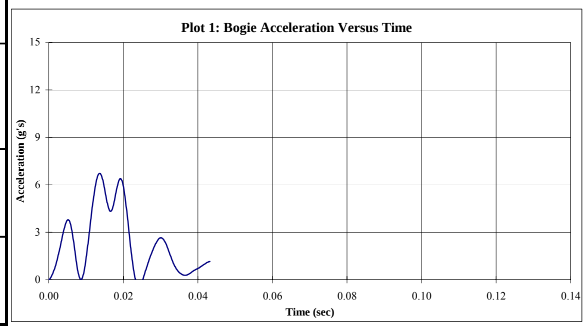


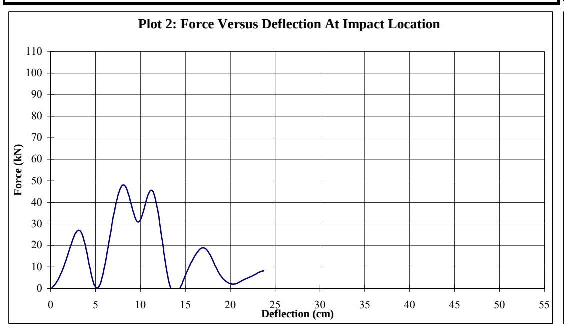
Figure 101. Results of Test No. SYPI-2

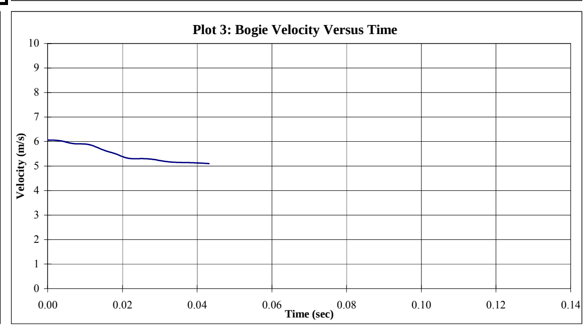
Midwest Roadside Safety Facility

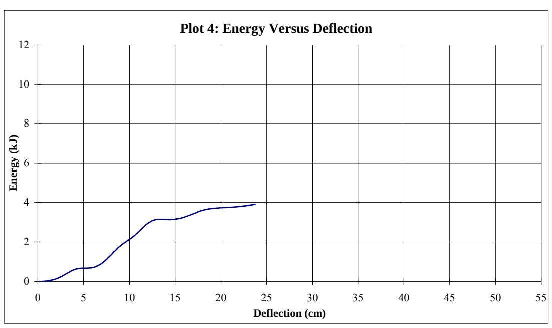
Bogie Test Summary

Test Information	0 degrees		
Test Number:	SYPI - 3		
Test Date:	7-Jun-2005		
Failure Type:			
	0		
Post Properties			
Post Type:	ıthern Yellow Pine		
Post Size:	8.415 cm diameter metric		7.25" diameter
Post Length:	198.1	cm	(78.0 in)
Embedment Depth:	99.1	cm	(39.0 in)
Soil Properties			
Gradation:	Steel Sleeve		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.6 mph)	(19.9 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side View-Digital		









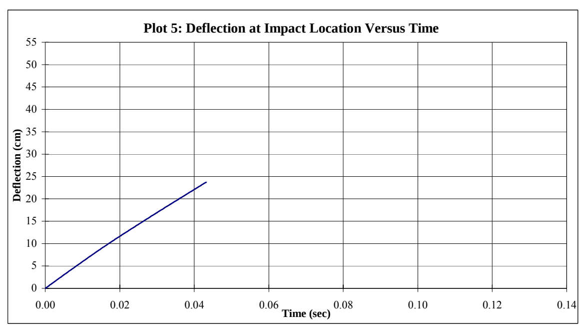


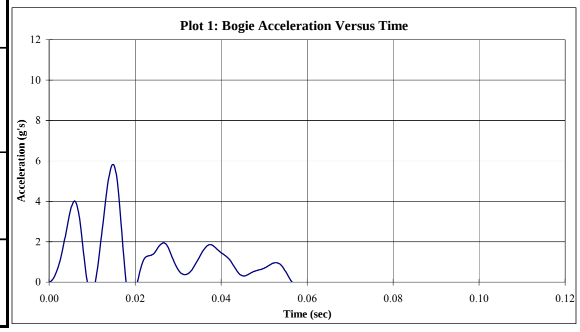
Figure 102. Results of Test No. SYPI-3

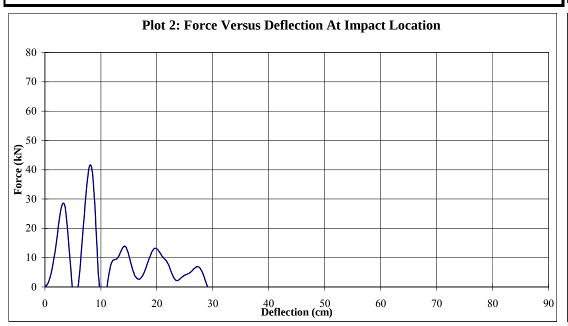
Appendix E. Round 2 Cantilever Bogie Test Results

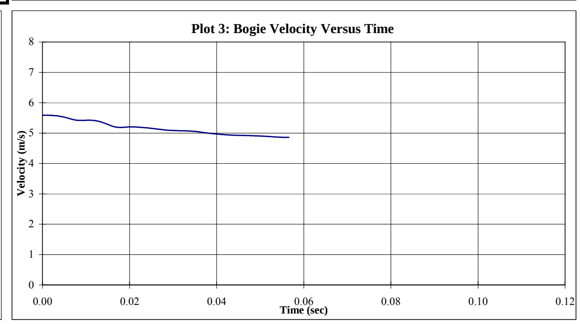
Midwest Roadside Safety Facility

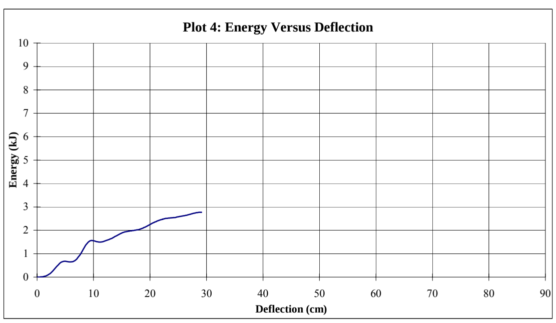
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-16		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	179.6 mm Dia.	metric	7.07 in. Dia.
Post Length:	198.4	cm	(503.9 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	5.6 m/s	(12.5 mph)	(18.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:			EDR-3
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









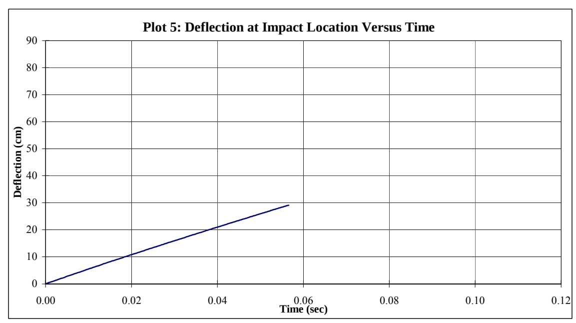
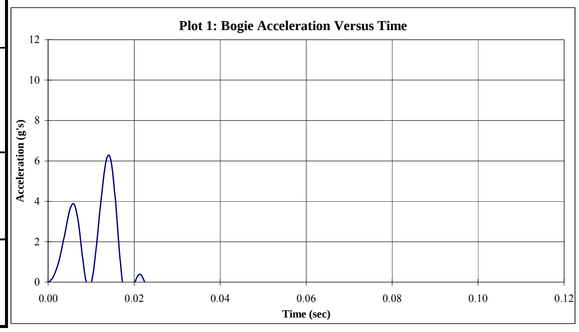


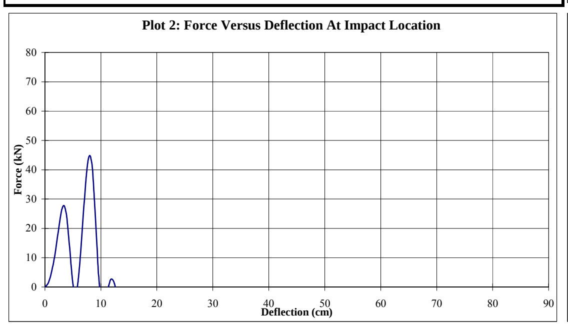
Figure 103. Results of Test No. PP-16

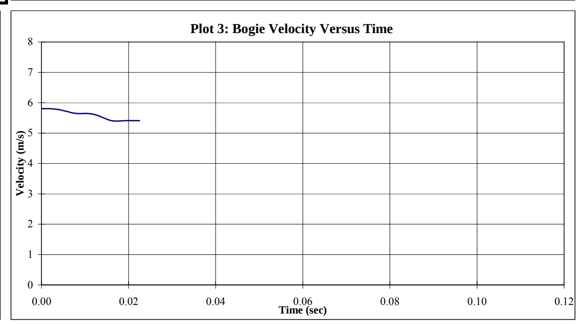
Midwest Roadside Safety Facility

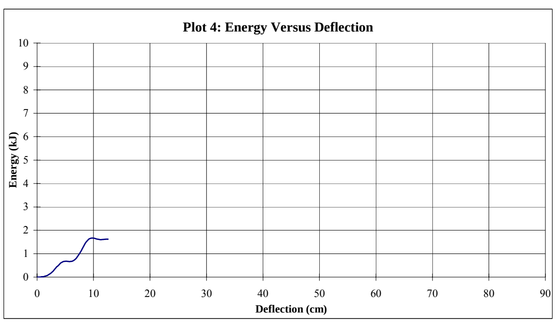
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-17		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	181.6 mm Dia.	metric	7.15 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	5.8 m/s	(13.0 mph)	(19.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









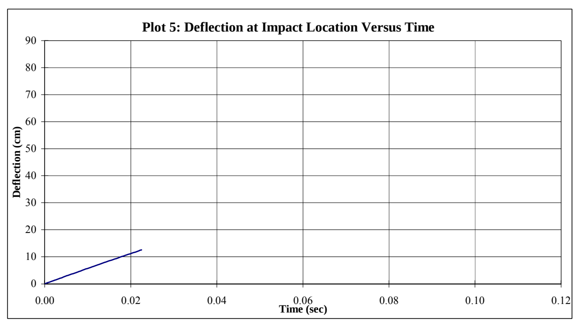
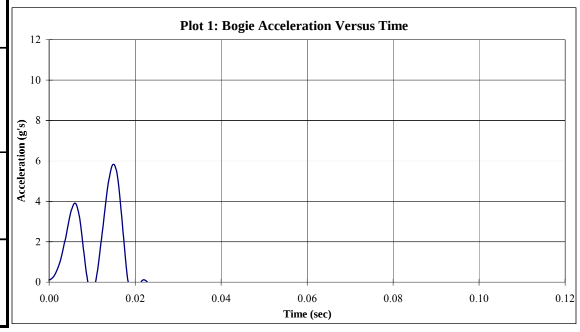
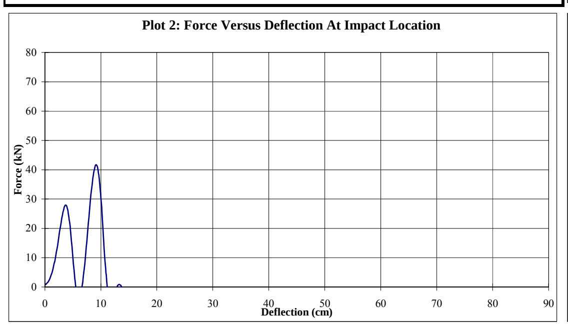


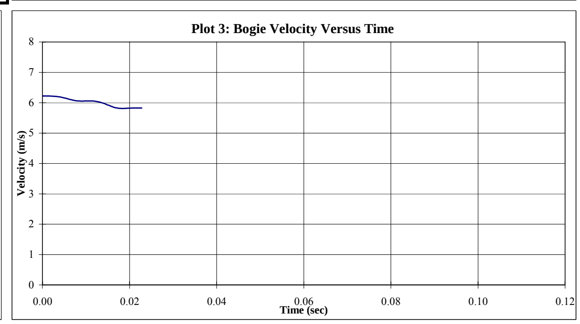
Figure 104. Results of Test No. PP-17

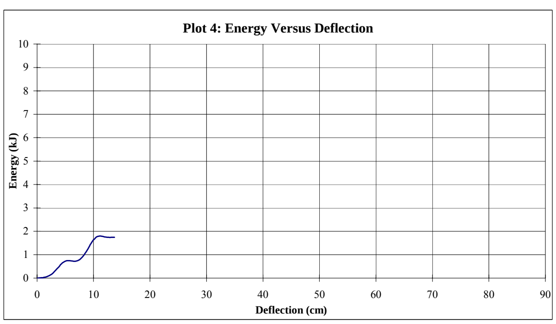
Midwest Roadside Safety Facility

Bogie Test Summary				
Test Information		CL Bogie MGS Height		
	Test Number:	PP-18		
	Test Date:	10-Aug-2005		
	Failure Type:	0		
Post Properties				
	Post Type:	Ponderosa Pine - Round Wooden		
	Post Size:	179.6 mm Dia.	metric	7.07 in. Dia.
	Post Length:	198.4	cm	(503.9 cm)
	Embedment Depth:	101.6	cm	(258.1 cm)
	Category:	Knots		
Soil Properties				
	Gradation:		NA	
	Moisture Content:		NA	
	Compaction Method:		NA	
	Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties				
	Impact Velocity:	6.2 m/s	(13.9 mph)	(20.4 fps)
	Impact Location:	63.2 cm	(24.9 in)	above groundline
	Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired				
	Accelerometer Data:		EDR-3	
	Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









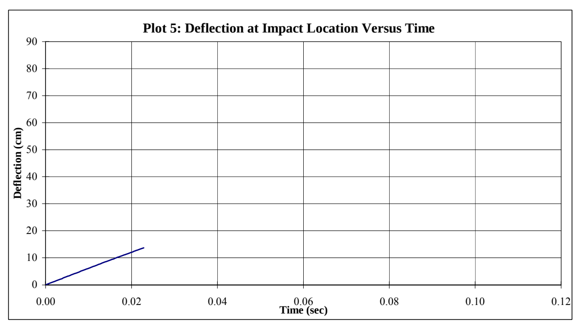
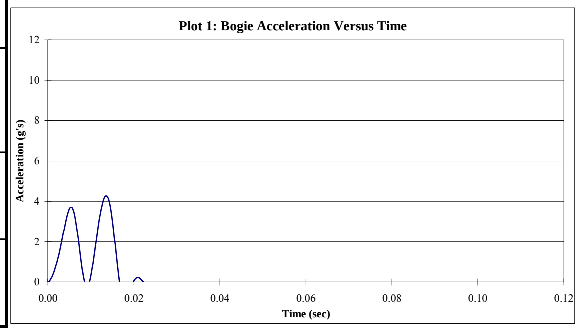
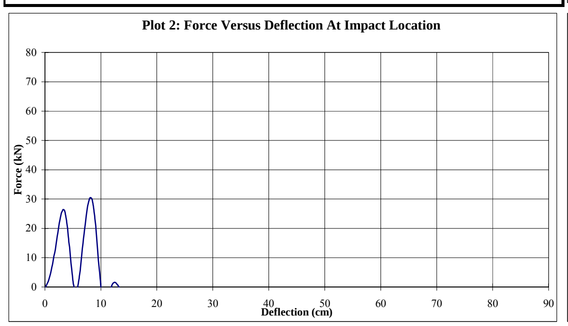


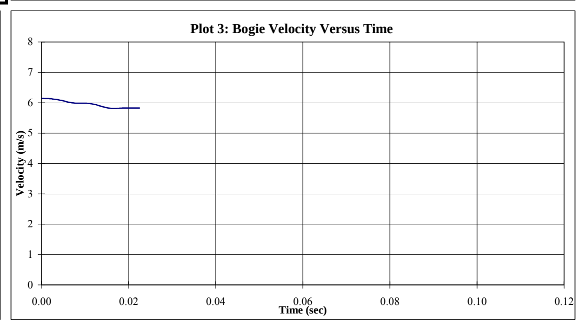
Figure 105. Results of Test No. PP-18

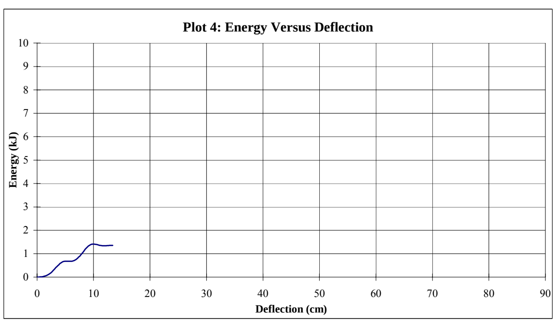
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-19		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	183.4 mm Dia.	metric	7.22 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.7 mph)	(20.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:			EDR-3
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









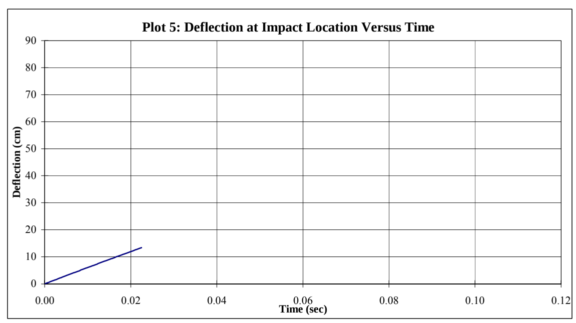
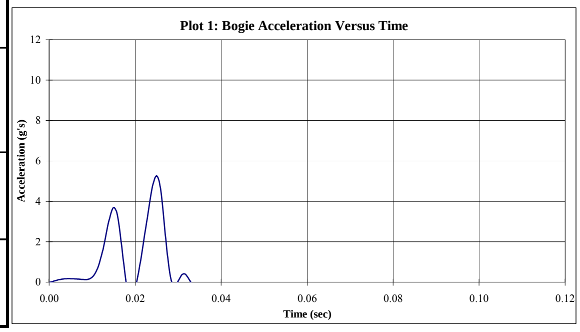
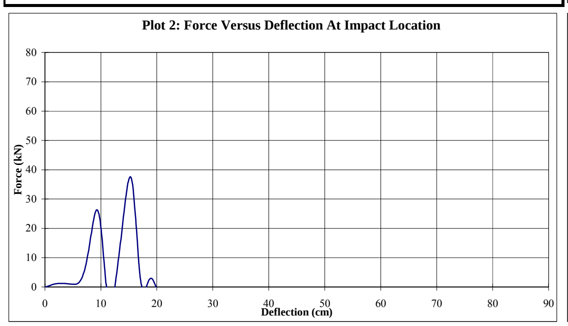


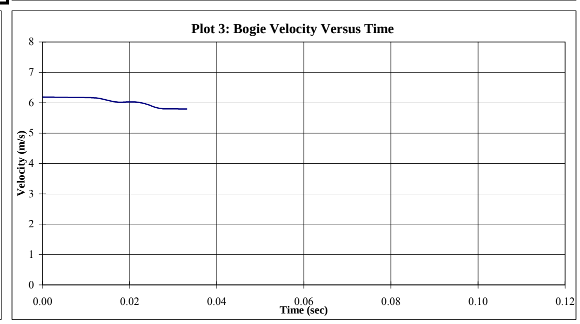
Figure 106. Results of Test No. PP-19

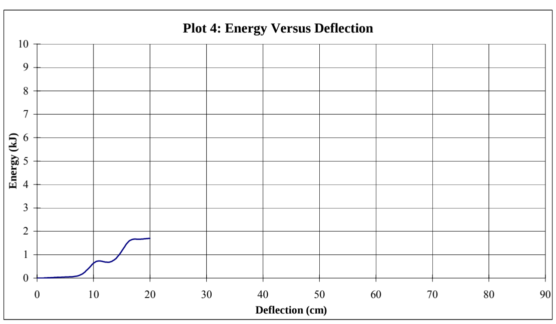
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-20		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	162.3 mm Dia.	metric	6.39 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		NA
Bogie Properties			
Impact Velocity:	6.2 m/s	(13.8 mph)	(20.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









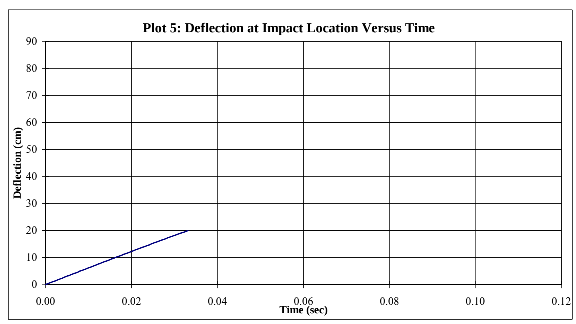
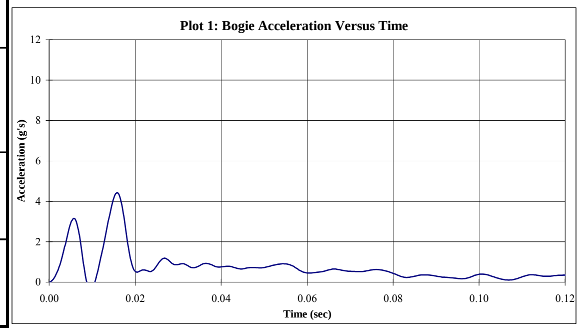


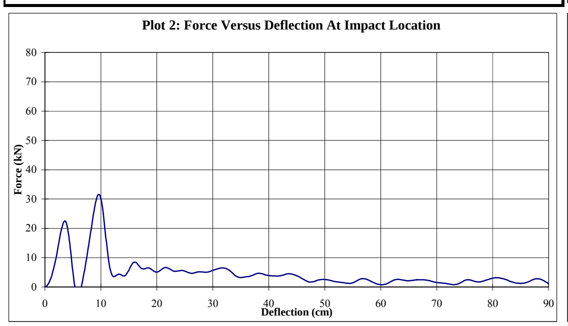
Figure 107. Results of Test No. PP-20

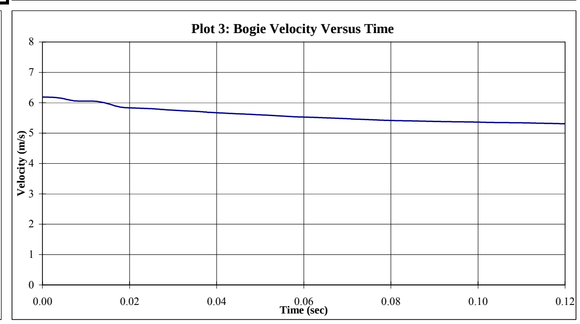
Midwest Roadside Safety Facility

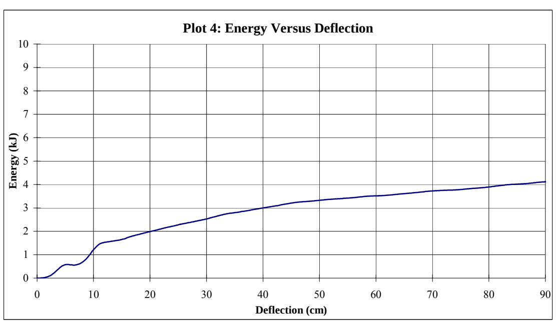
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-21		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	161.0 mm Dia.	metric	6.34 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Baseline		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	6.2 m/s	(13.8 mph)	(20.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









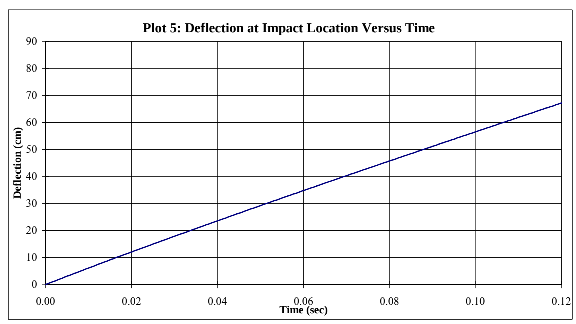
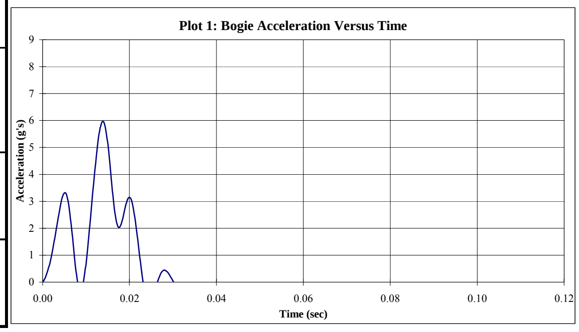


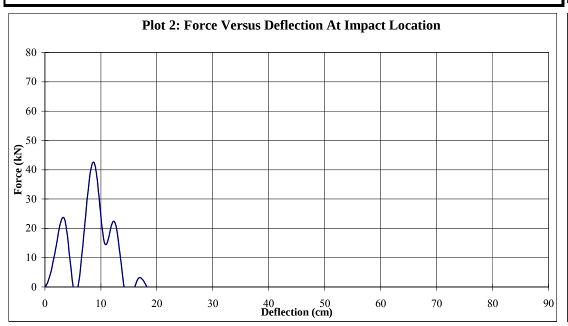
Figure 108. Results of Test No. PP-21

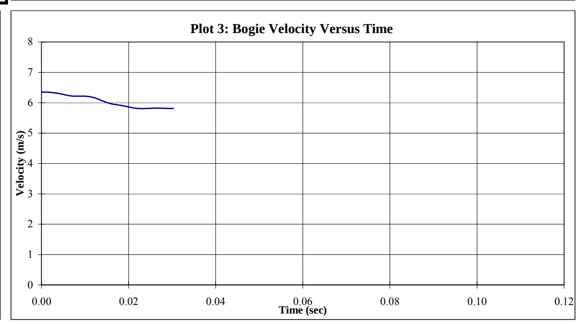
Midwest Roadside Safety Facility

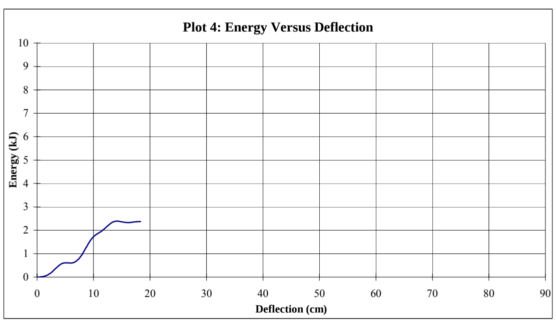
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-22		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	168.4 mm Dia.	metric	6.63 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Baseline		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	6.3 m/s	(14.2 mph)	(20.8 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:			EDR-3
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









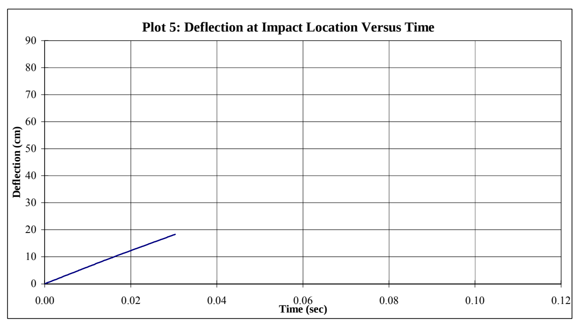
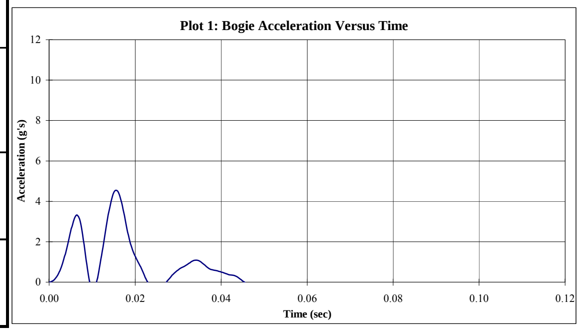


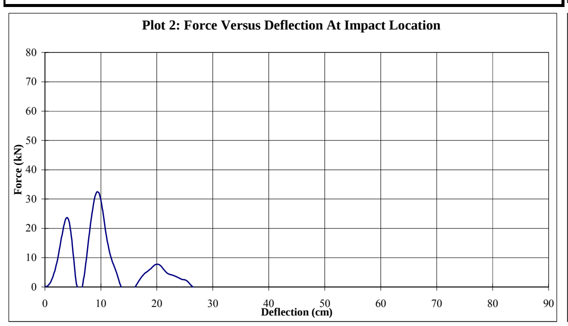
Figure 109. Results of Test No. PP-22

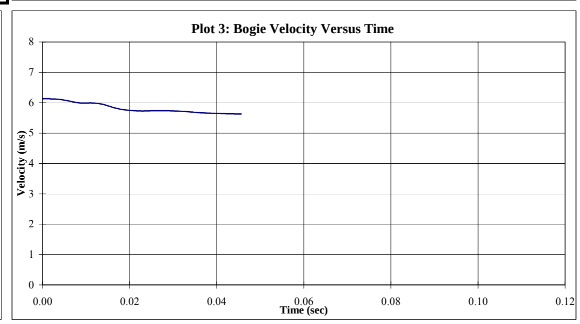
Midwest Roadside Safety Facility

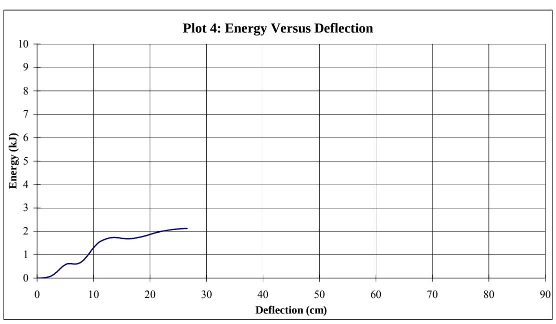
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-23		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	174.5 mm Dia.	metric	6.87 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Baseline		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.7 mph)	(20.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









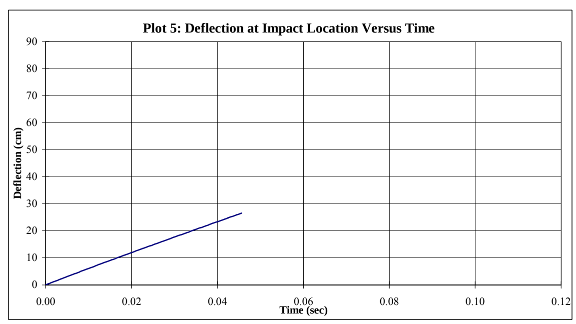
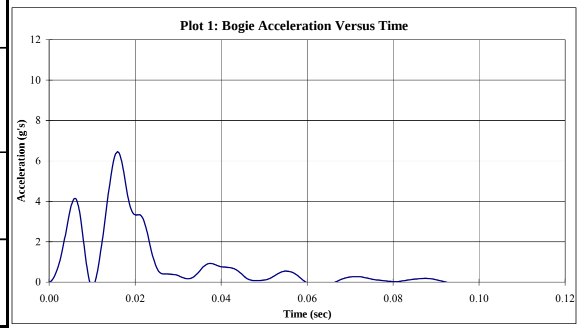


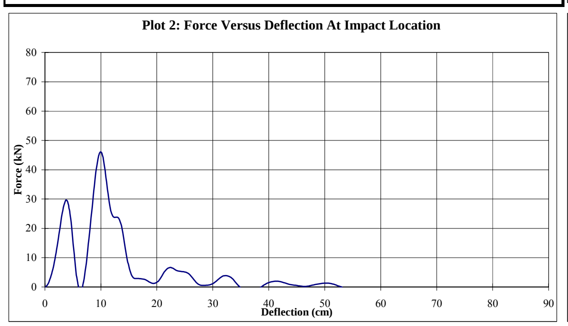
Figure 110. Results of Test No. PP-23

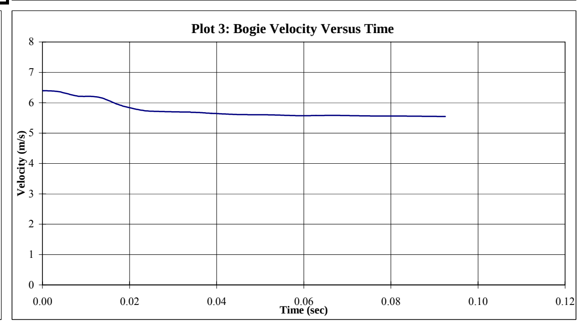
Midwest Roadside Safety Facility

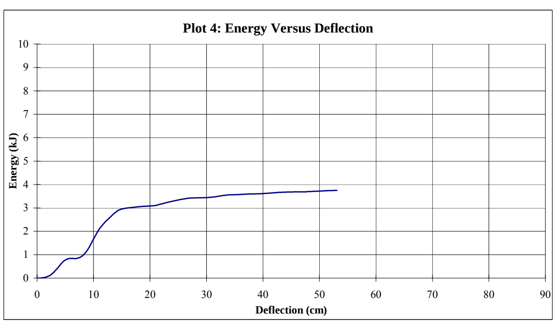
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-24		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	171.5 mm Dia. metric	6.75 in. Dia.	
Post Length:	198.4 cm	(503.9 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	Baseline		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	6.4 m/s	(14.3 mph)	(21.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









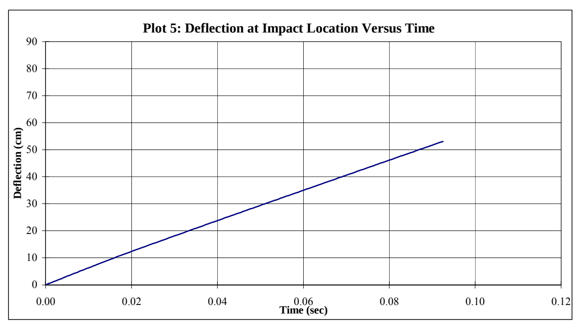
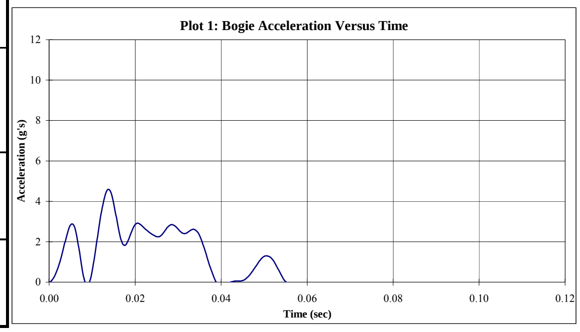


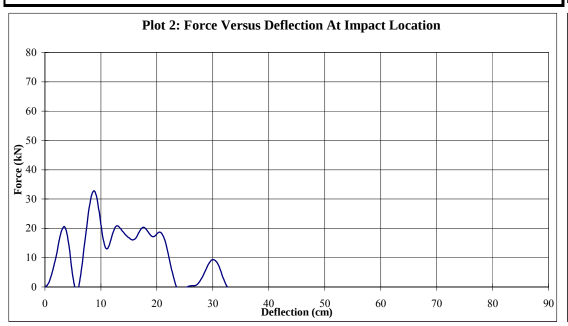
Figure 111. Results of Test No. PP-24

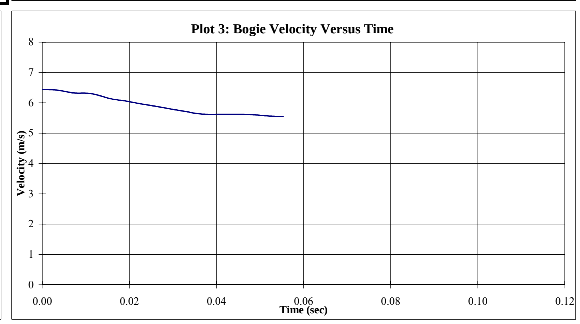
Midwest Roadside Safety Facility

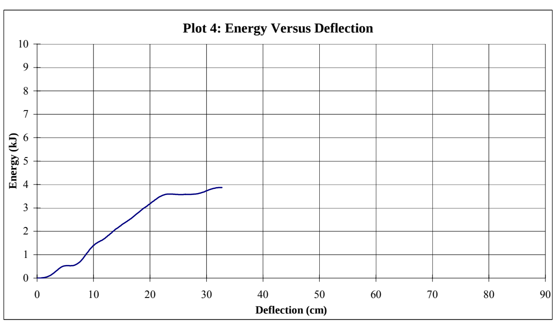
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	PP-25	
Test Date:	10-Aug-2005	
Failure Type:	0	
Post Properties		
Post Type:	Ponderosa Pine - Round Wooden	
Post Size:	163.8 mm Dia. metric	6.45 in. Dia.
Post Length:	198.6 cm	(504.5 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	Baseline	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	6.4 m/s	(14.4 mph) (21.1 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron	









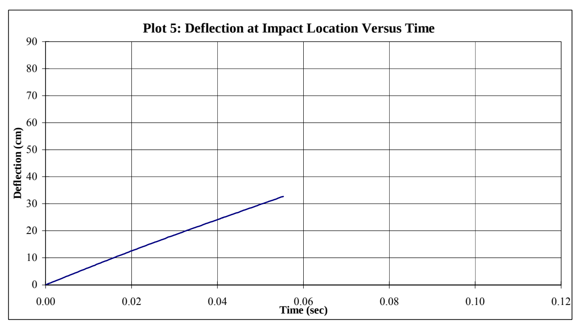
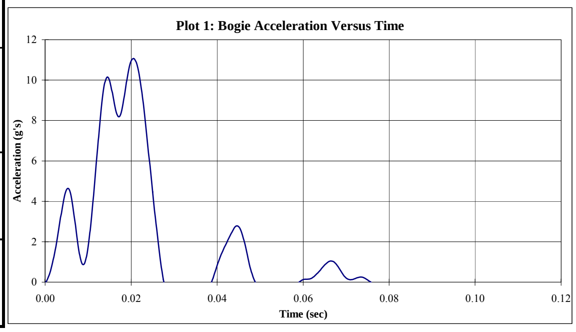


Figure 112. Results of Test No. PP-25

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-26		
Test Date:	10-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	192.8 mm Dia.	metric	7.59 in. Dia.
Post Length:	198.1 cm		(503.2 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	6.3 m/s	(14.0 mph)	(20.6 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		



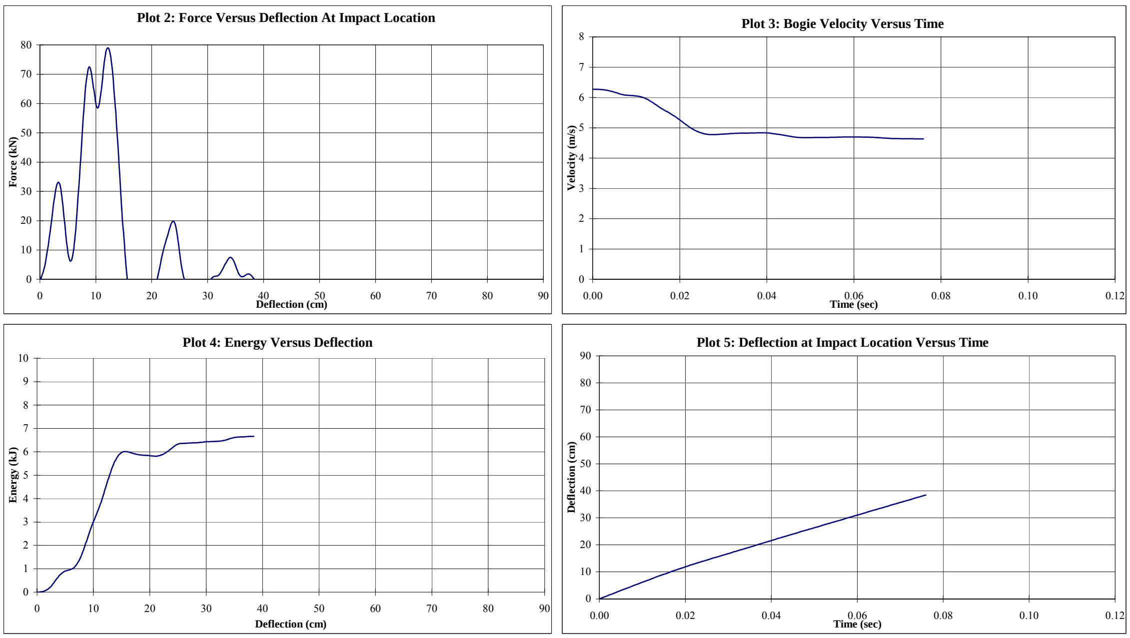
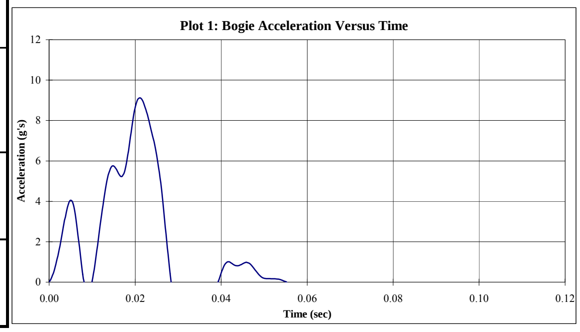


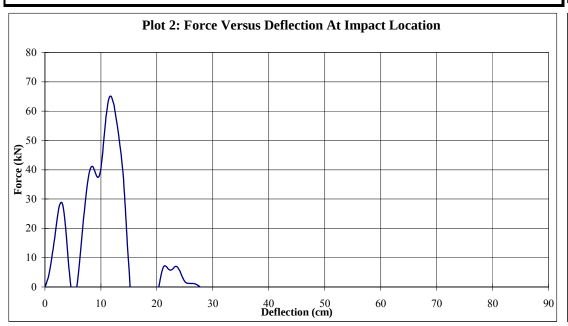
Figure 113. Results of Test No. PP-26

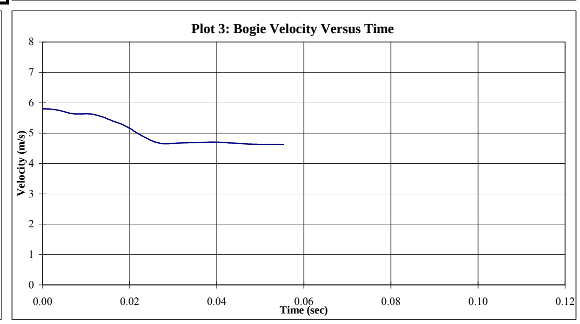
Midwest Roadside Safety Facility

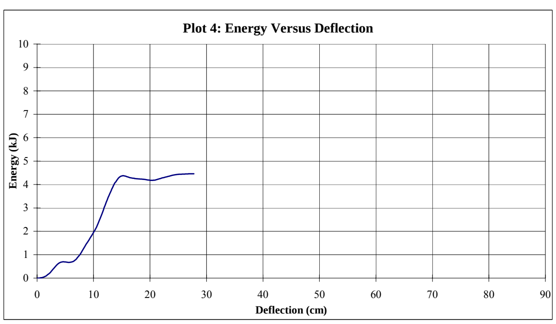
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-27		
Test Date:	11-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	191.8 mm Dia.	metric	7.55 in. Dia.
Post Length:	198.4 cm		(503.9 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	5.8 m/s	(13.0 mph)	(19.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









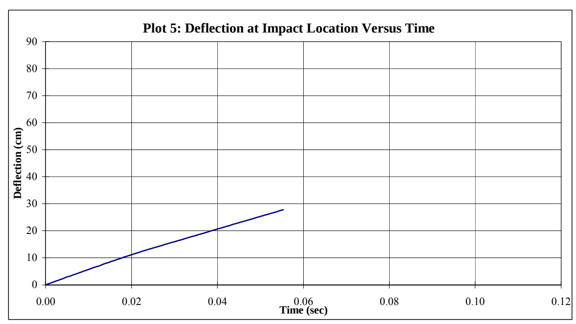
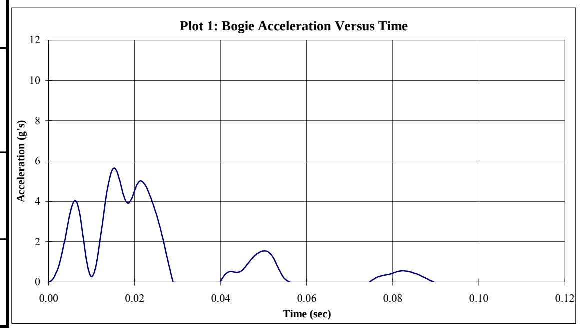


Figure 114. Results of Test No. PP-27

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-28		
Test Date:	11-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	180.8 mm Dia.	metric	7.12 in. Dia.
Post Length:	198.4 cm		(503.9 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		NA
Bogie Properties			
Impact Velocity:	6.2 m/s	(13.9 mph)	(20.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		



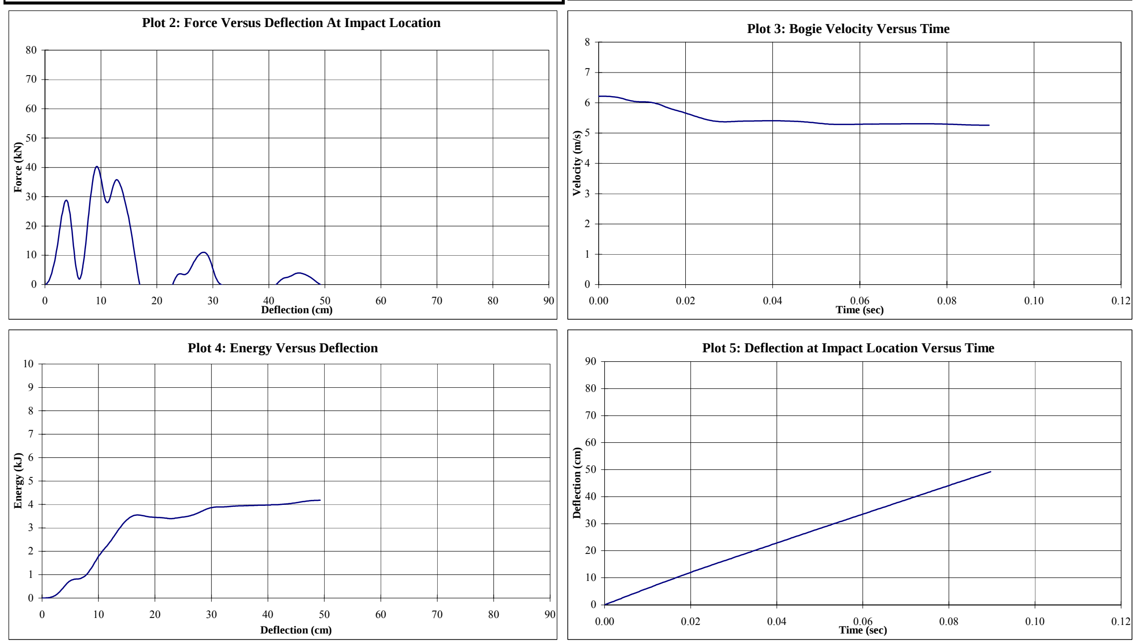
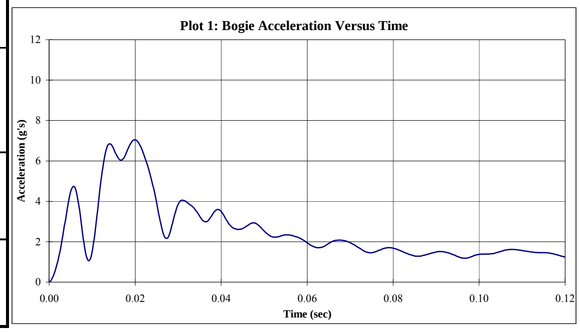
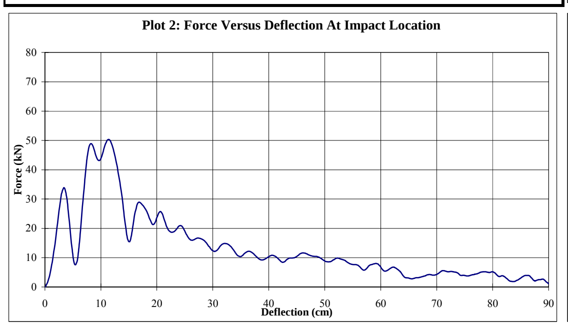


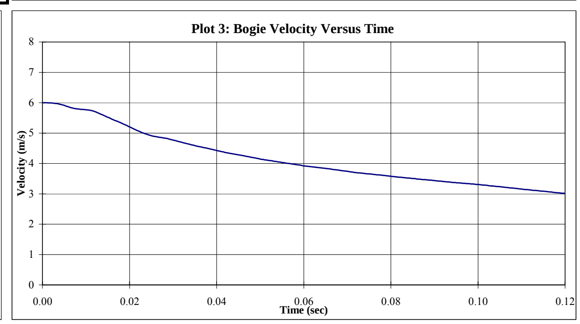
Figure 115. Results of Test No. PP-28

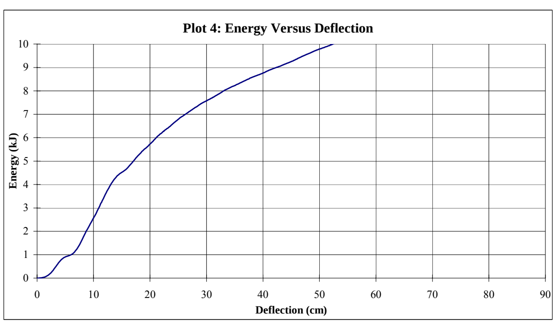
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-29		
Test Date:	11-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	188.2 mm Dia.	metric	7.41 in. Dia.
Post Length:	198.4 cm		(503.9 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³		NA
Bogie Properties			
Impact Velocity:	6.0 m/s	(13.4 mph)	(19.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









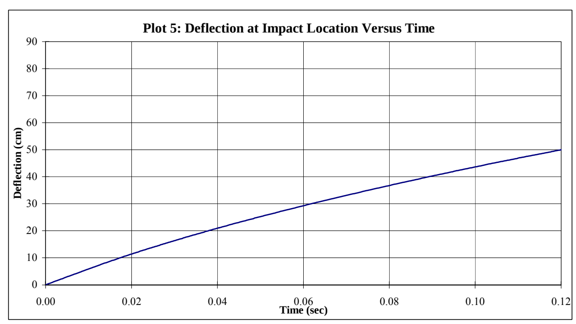
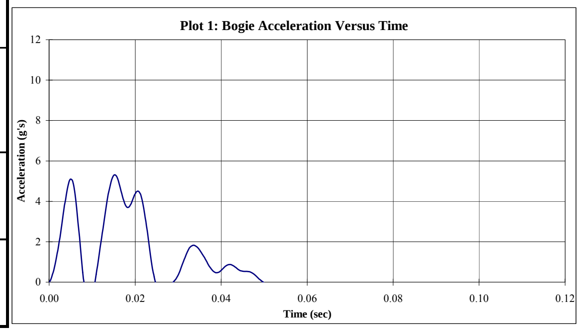


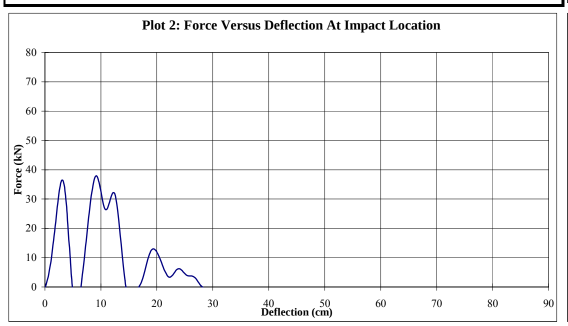
Figure 116. Results of Test No. PP-29

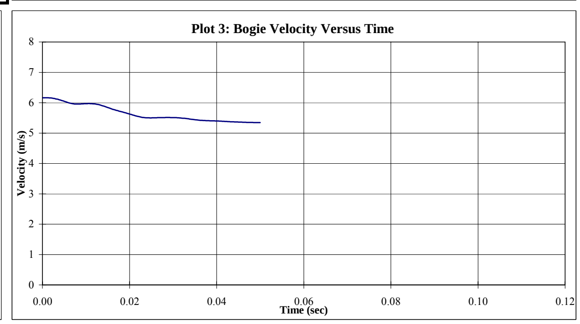
Midwest Roadside Safety Facility

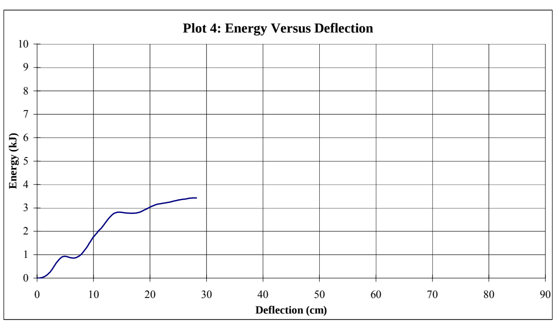
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	PP-30	
Test Date:	11-Aug-2005	
Failure Type:	0	
Post Properties		
Post Type:	Ponderosa Pine - Round Wooden	
Post Size:	186.7 mm Dia. metric	7.35 in. Dia.
Post Length:	198.4 cm	(503.9 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	HRD	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	6.2 m/s	(13.8 mph) (20.2 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron	









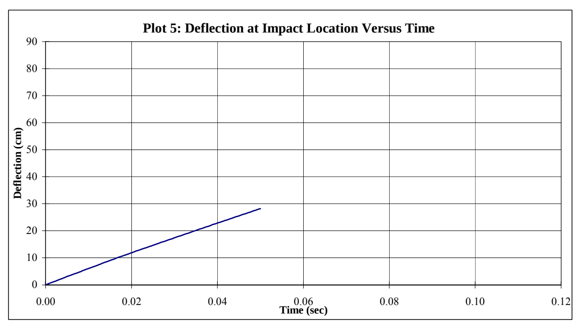
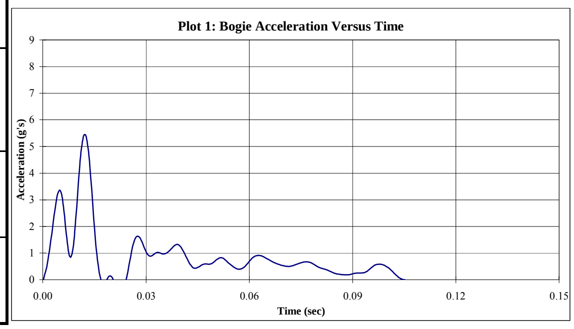


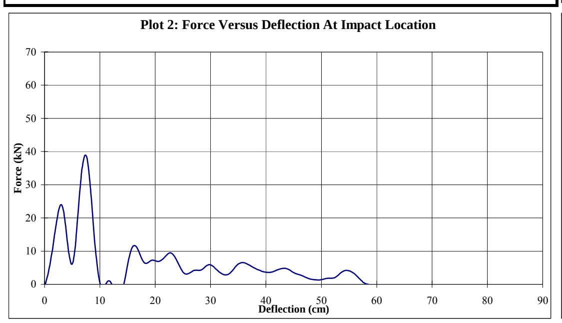
Figure 117. Results of Test No. PP-30

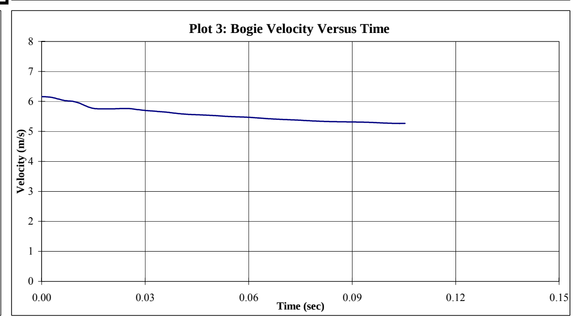
Midwest Roadside Safety Facility

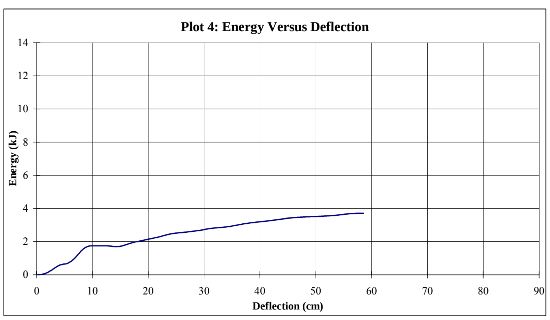
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-16		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	161.0 mm Dia. metric	6.34 in. Dia.	
Post Length:	198.4 cm	(503.9 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	Knots		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	6.2 m/s	(13.8 mph)	(20.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	:w-DV, AOS-1, AOS-2, and Photron		









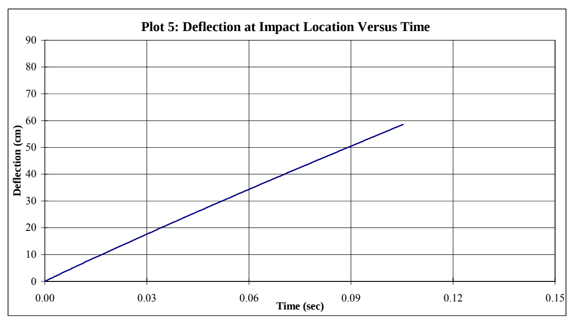
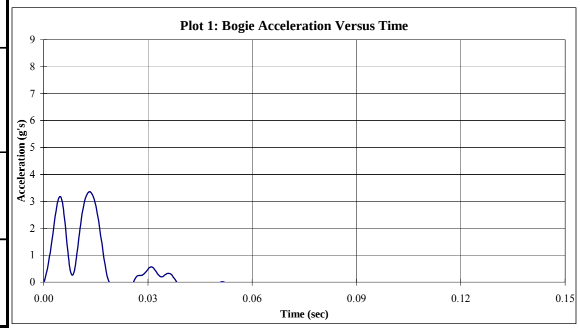


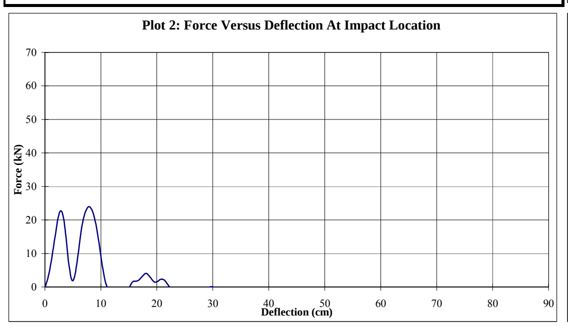
Figure 118. Results of Test No. DF-16

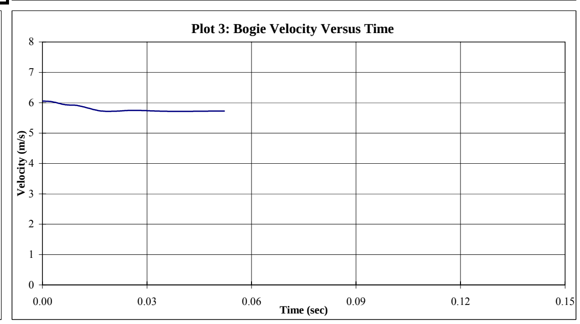
Midwest Roadside Safety Facility

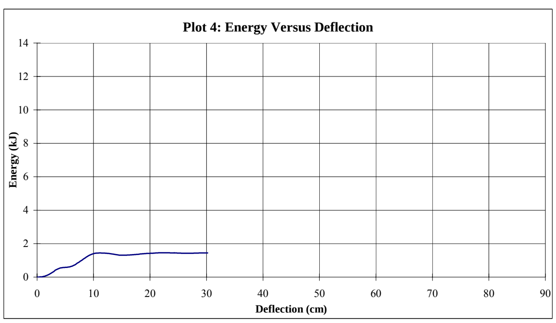
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-17		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	182.4 mm Dia.	metric	7.18 in. Dia.
Post Length:	198.6	cm	(504.5 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.5 mph)	(19.9 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:			EDR-3
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









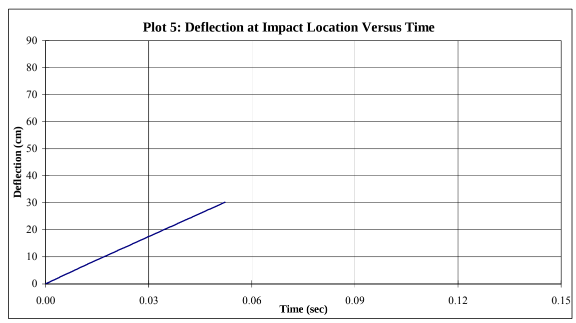
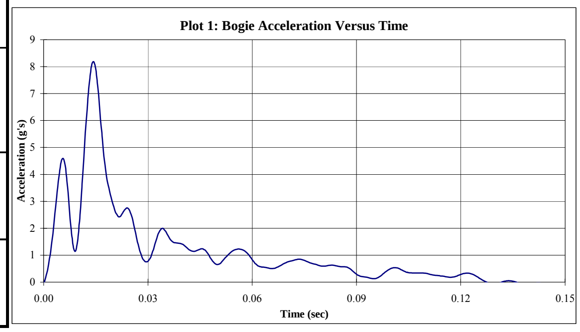


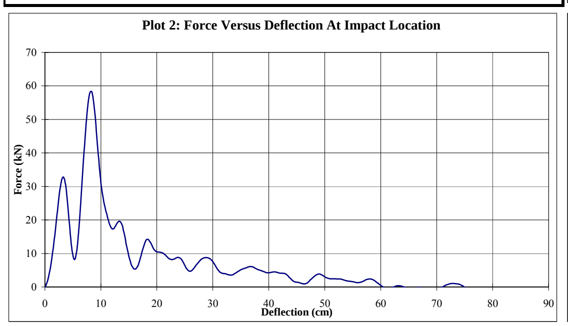
Figure 119. Results of Test No. DF-17

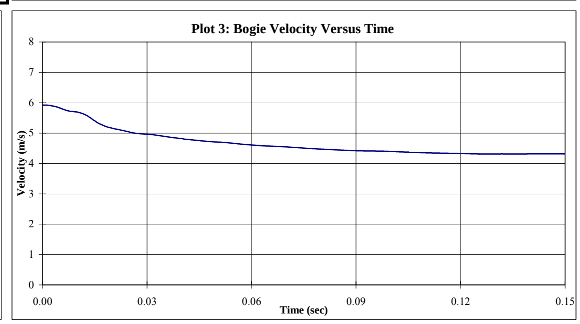
Midwest Roadside Safety Facility

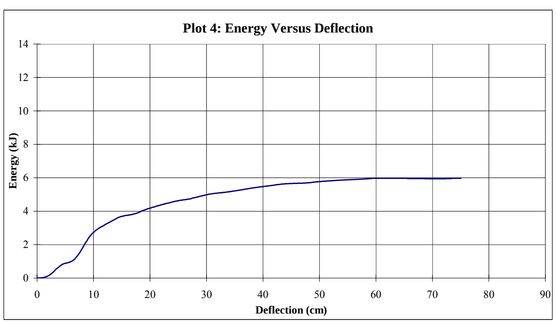
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-18		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	178.6 mm Dia.	metric	7.03 in. Dia.
Post Length:	198.6 cm		(504.5 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	NA
Bogie Properties			
Impact Velocity:	5.9 m/s	(13.2 mph)	(19.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









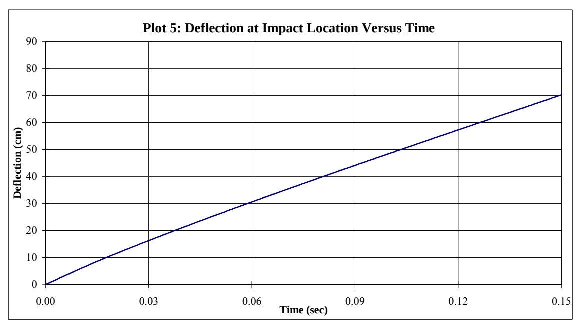
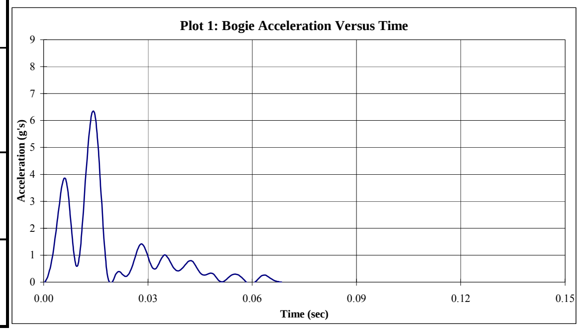


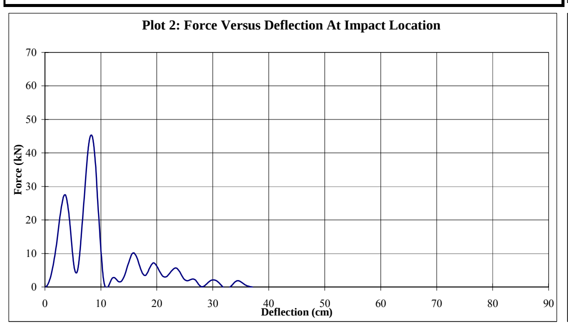
Figure 120. Results of Test No. DF-18

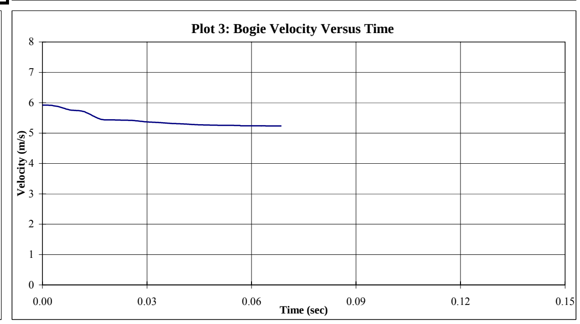
Midwest Roadside Safety Facility

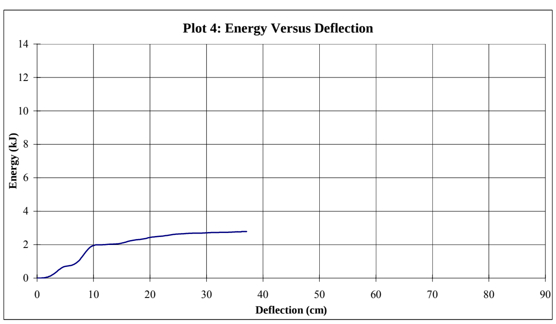
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-19		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	172.7 mm Dia.	metric	6.80 in. Dia.
Post Length:	198.4 cm		(503.9 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	5.9 m/s	(13.2 mph)	(19.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









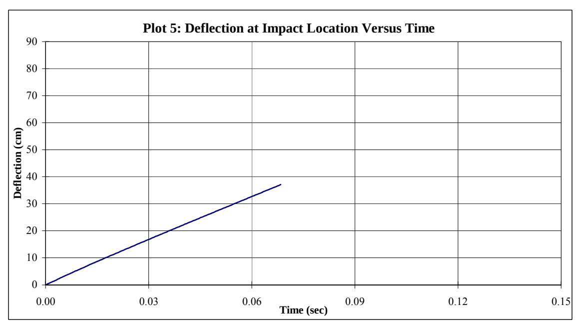
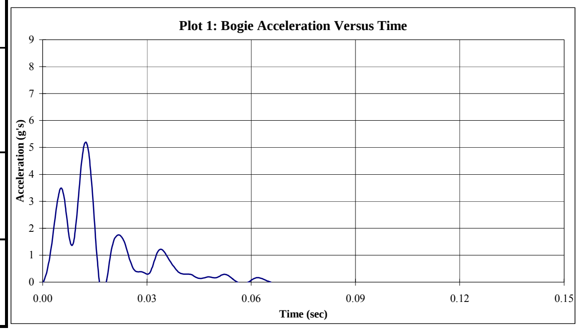
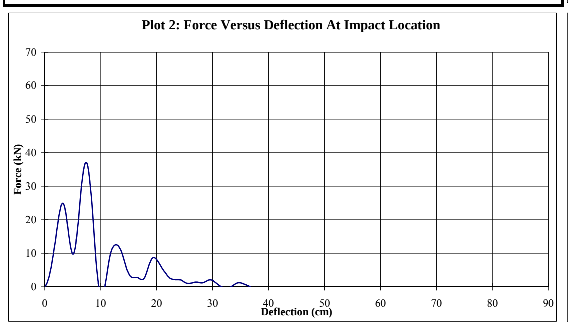


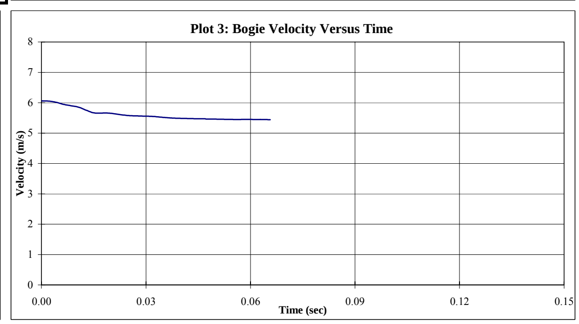
Figure 121. Results of Test No. DF-19

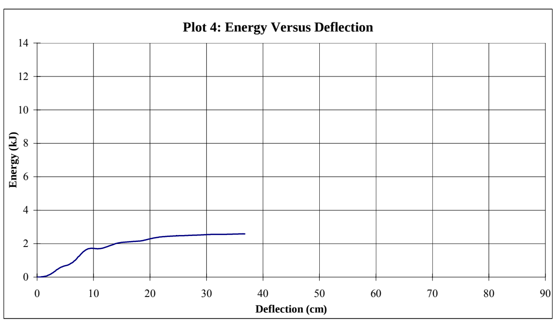
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-20		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	180.3 mm Dia.	metric	7.10 in. Dia.
Post Length:	198.6	cm	(504.5 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	Knots		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.6 mph)	(19.9 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









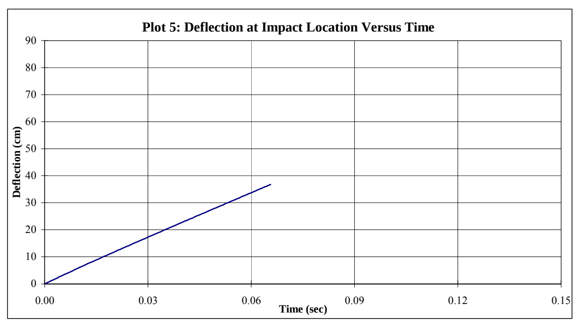
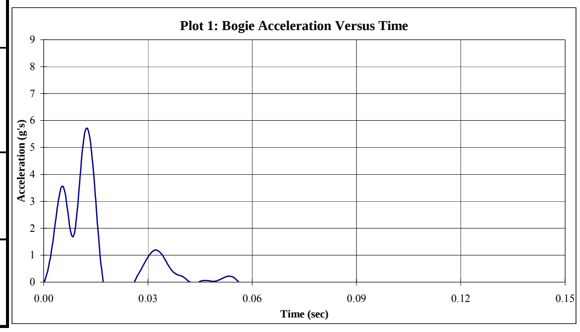


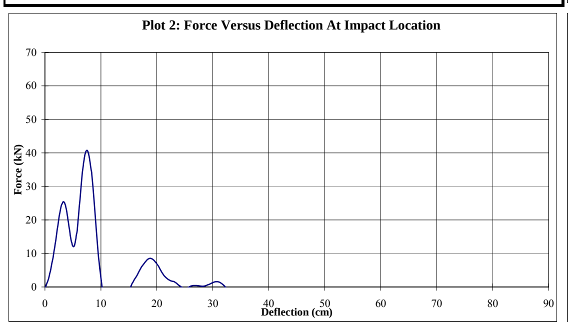
Figure 122. Results of Test No. DF-20

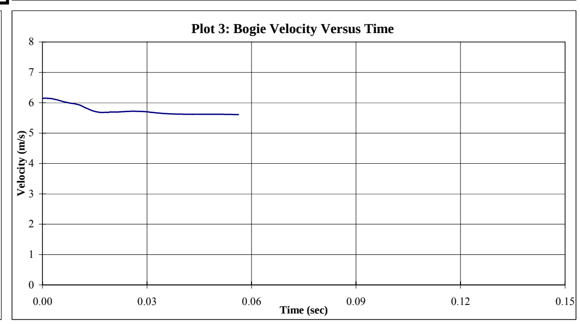
Midwest Roadside Safety Facility

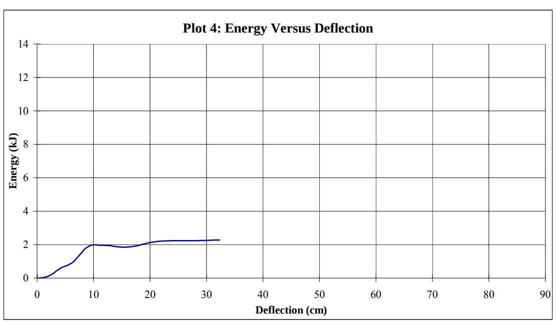
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-21		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	200.2 mm Dia. metric	7.88 in. Dia.	
Post Length:	198.4 cm	(503.9 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	Baseline		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3	NA	
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.8 mph)	(20.2 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









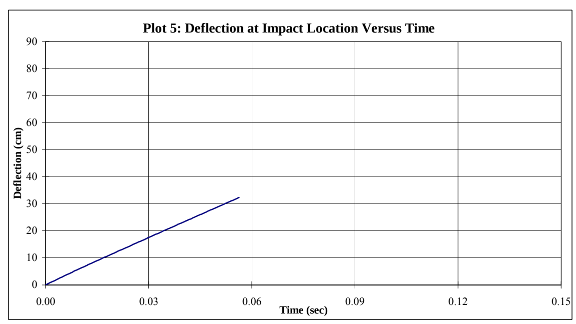
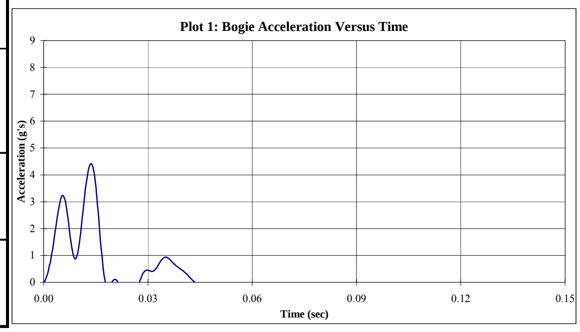


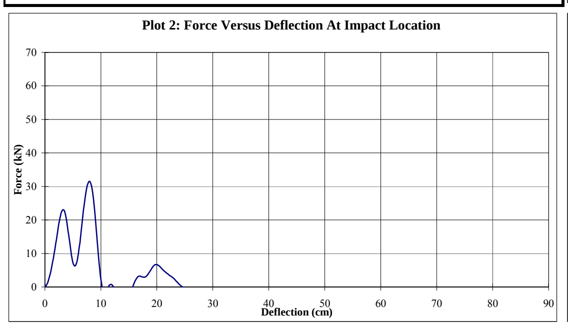
Figure 123. Results of Test No. DF-21

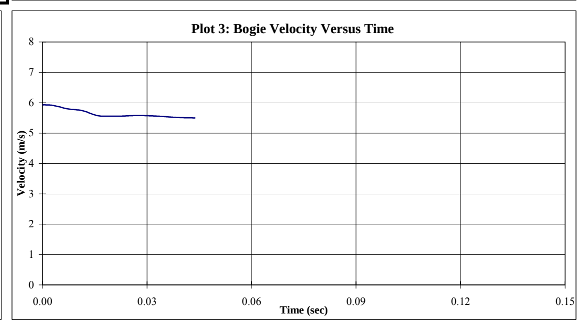
Midwest Roadside Safety Facility

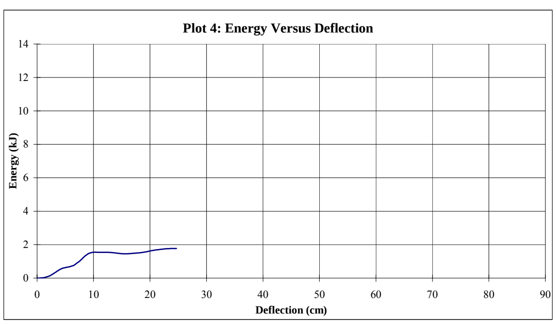
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	DF-22	
Test Date:	8-Aug-2005	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	176.3 mm Dia. metric	6.94 in. Dia.
Post Length:	198.4 cm	(503.9 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	Baseline	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	5.9 m/s	(13.3 mph) (19.4 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron	









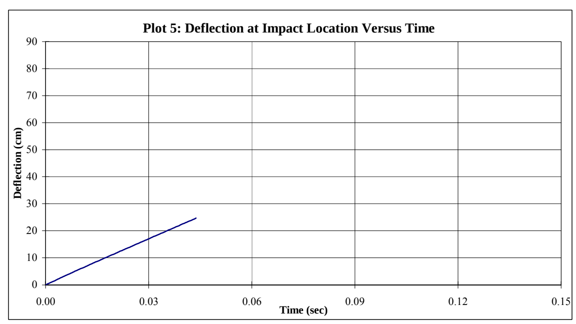
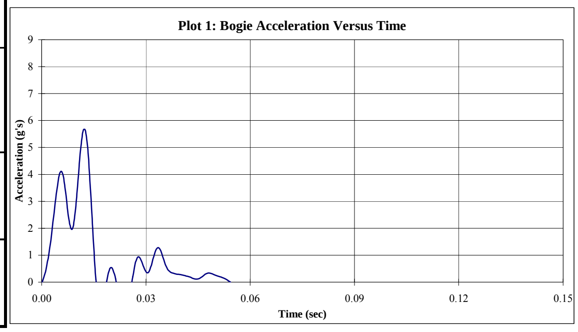


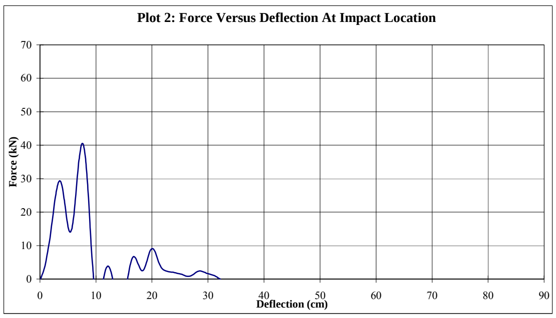
Figure 124. Results of Test No. DF-22

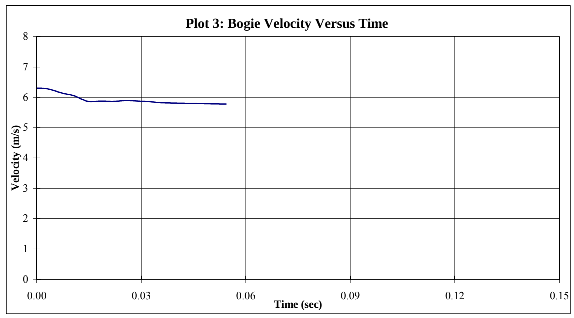
Midwest Roadside Safety Facility

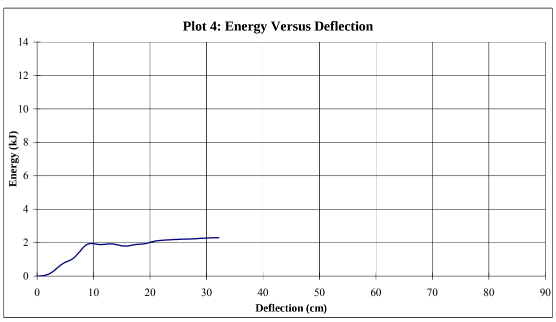
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-23		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	167.6 mm Dia. metric	6.60 in. Dia.	
Post Length:	198.4 cm	(503.9 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	Baseline		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	6.3 m/s	(14.1 mph)	(20.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









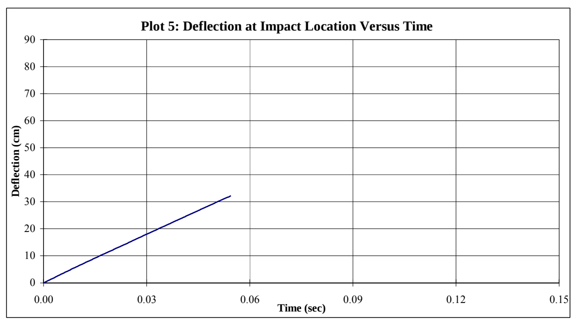
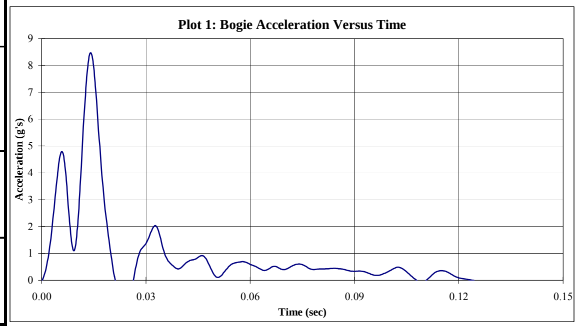


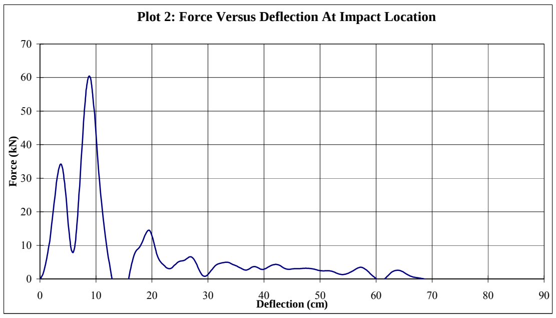
Figure 125. Results of Test No. DF-23

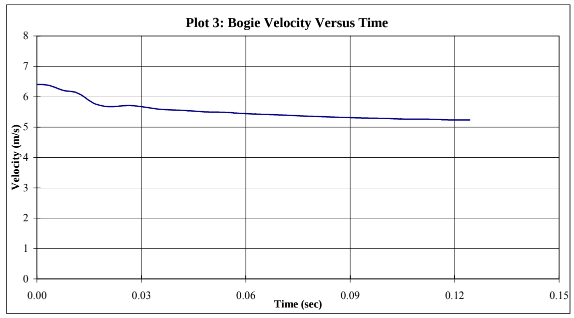
Midwest Roadside Safety Facility

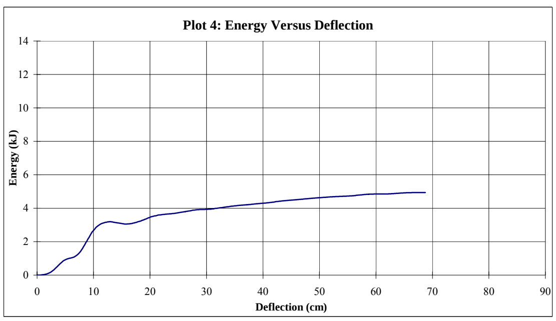
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	DF-24	
Test Date:	8-Aug-2005	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	186.7 mm Dia. metric	7.35 in. Dia.
Post Length:	198.4 cm	(503.9 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	Baseline	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	6.4 m/s	(14.3 mph) (21.0 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron	









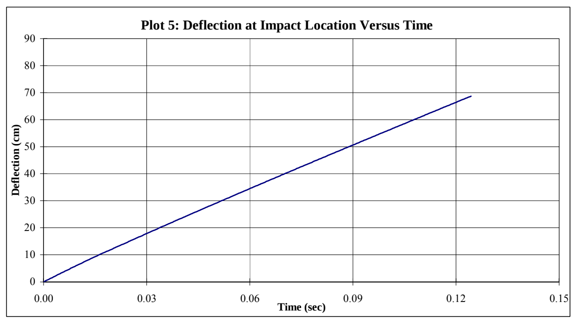
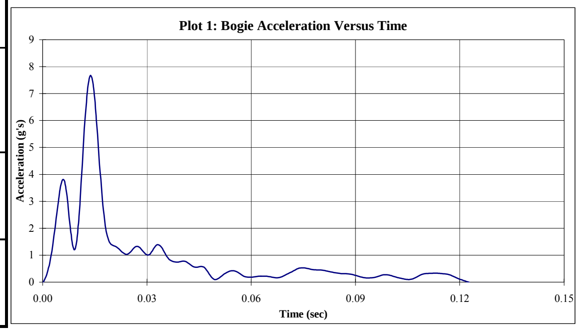


Figure 126. Results of Test No. DF-24

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-25		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	179.6 mm Dia.	metric	7.07 in. Dia.
Post Length:	198.6 cm		(504.5 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	Baseline		
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	5.8 m/s	(13.0 mph)	(19.0 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		



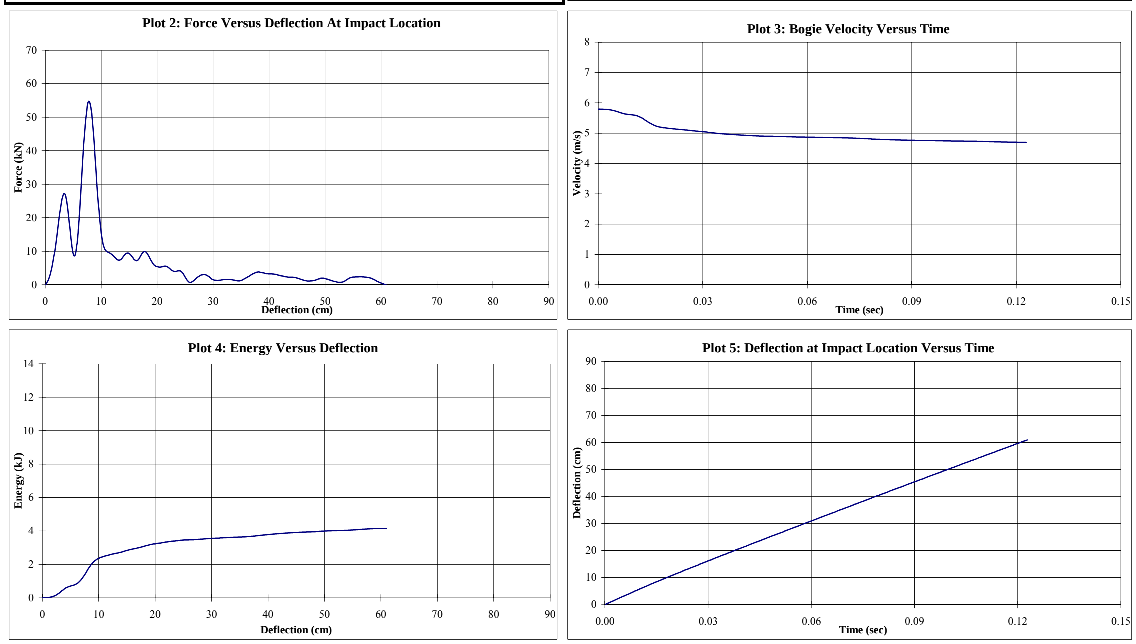
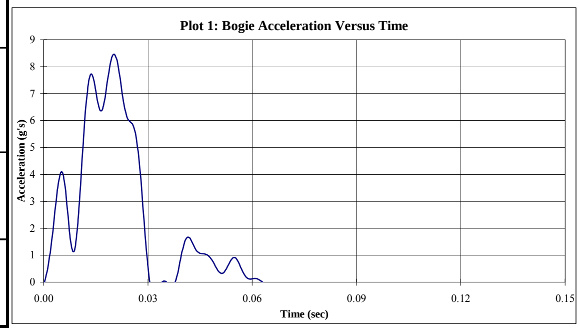


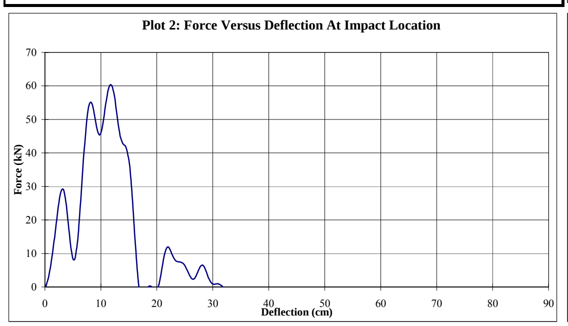
Figure 127. Results of Test No. DF-25

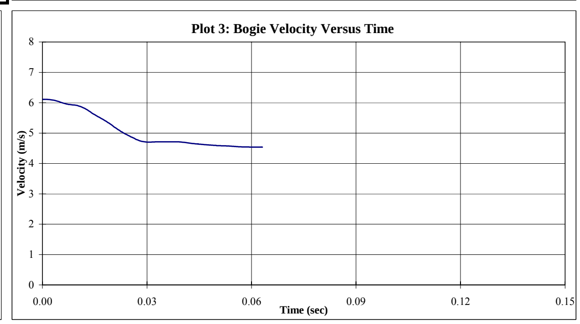
Midwest Roadside Safety Facility

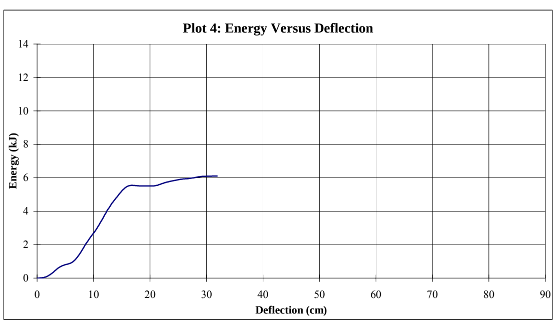
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-26		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	177.3 mm Dia.	metric	6.98 in. Dia.
Post Length:	198.4 cm		(503.9 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	6.1 m/s	(13.7 mph)	(20.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









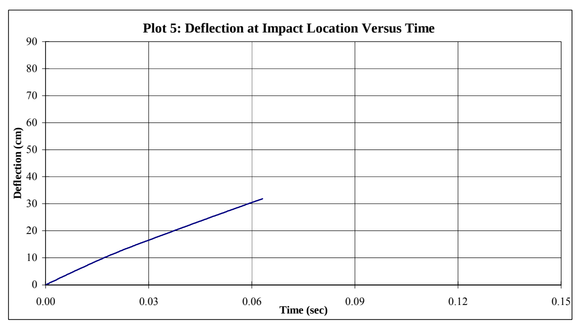
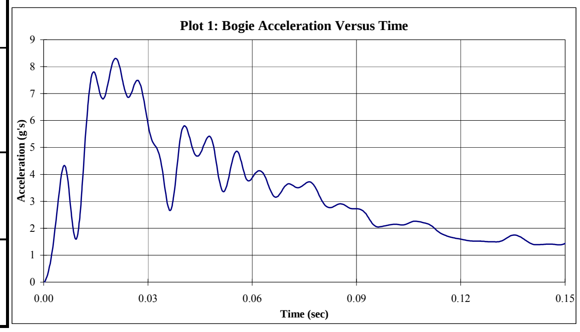


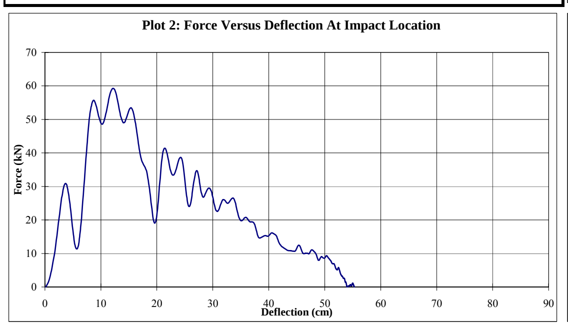
Figure 128. Results of Test No. DF-26

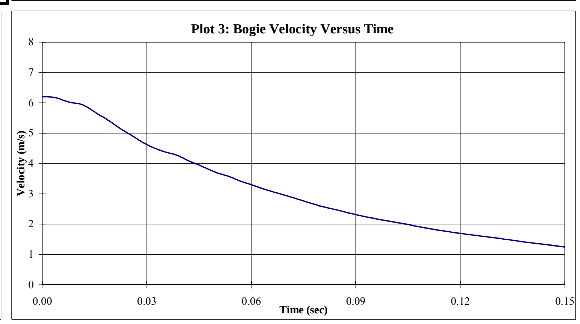
Midwest Roadside Safety Facility

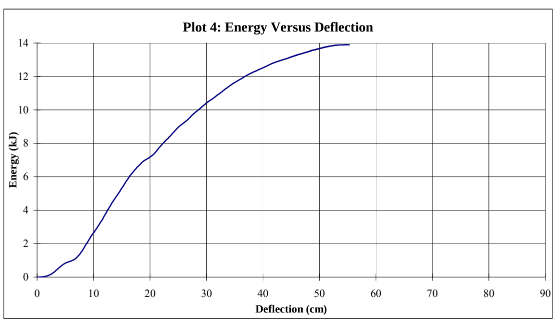
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-27		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	173.5 mm Dia. metric	6.83 in. Dia.	
Post Length:	198.4 cm	(503.9 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	6.2 m/s	(13.9 mph)	(20.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









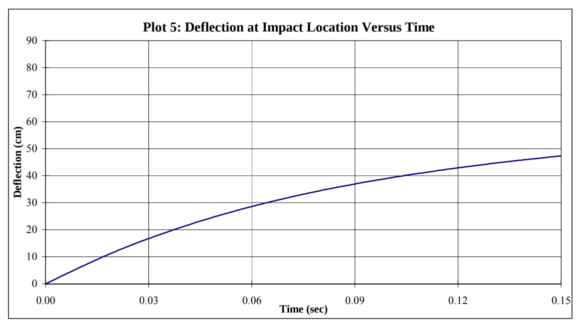
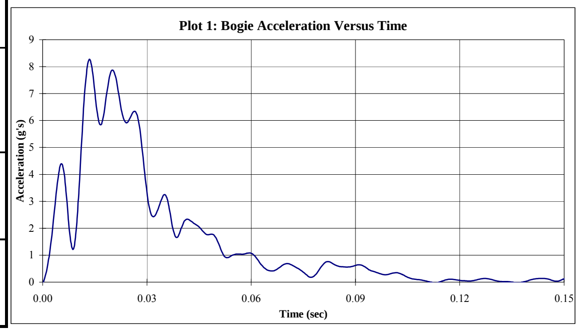
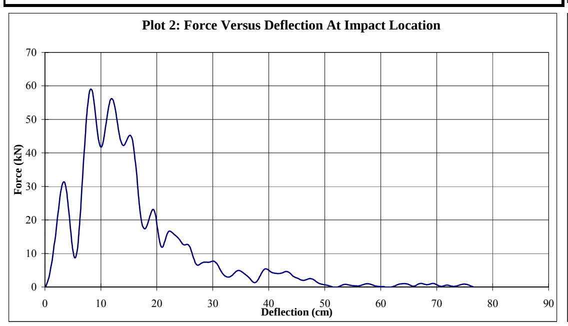


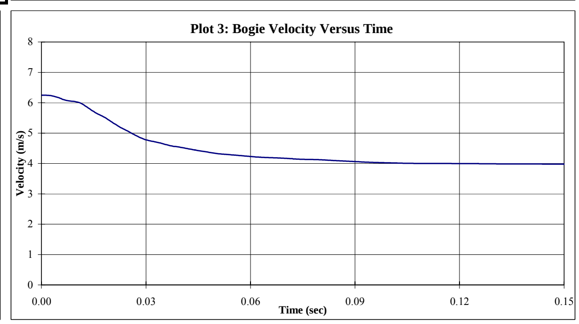
Figure 129. Results of Test No. DF-27

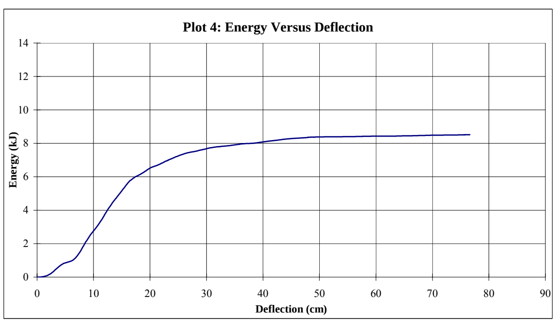
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-28		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	170.4 mm Dia. metric	6.71 in. Dia.	
Post Length:	198.6 cm	(504.5 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	HRD		
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	NA	
Bogie Properties			
Impact Velocity:	6.2 m/s	(14.0 mph)	(20.5 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		









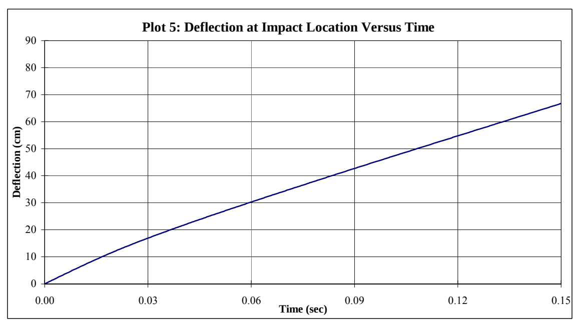
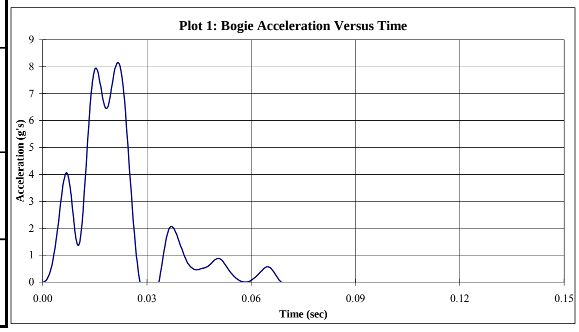
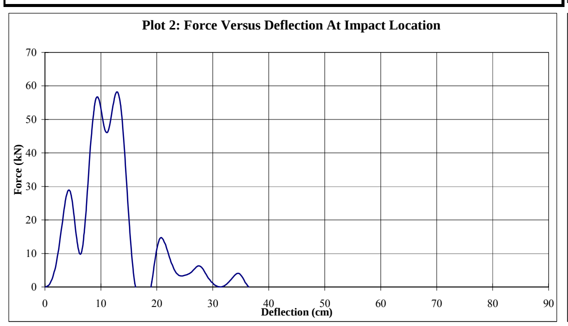


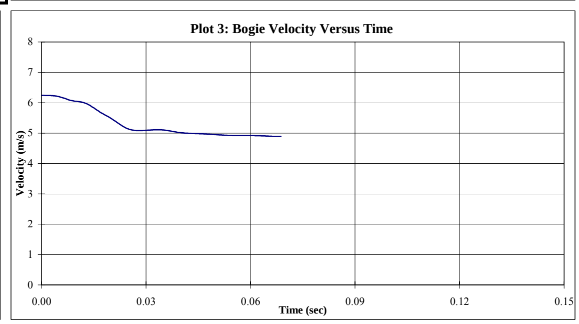
Figure 130. Results of Test No. DF-28

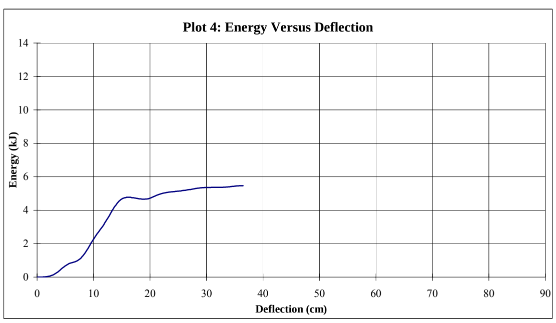
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	DF-29	
Test Date:	8-Aug-2005	
Failure Type:	0	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	178.3 mm Dia. metric	7.02 in. Dia.
Post Length:	198.4 cm	(503.9 cm)
Embedment Depth:	101.6 cm	(258.1 cm)
Category:	HRD	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γ_d:	NA kg/m^3	NA
Bogie Properties		
Impact Velocity:	6.2 m/s (14.0 mph)	(20.5 fps)
Impact Location:	63.2 cm (24.9 in)	above groundline
Bogie Mass:	728 kg (1605 lbf)	
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron	









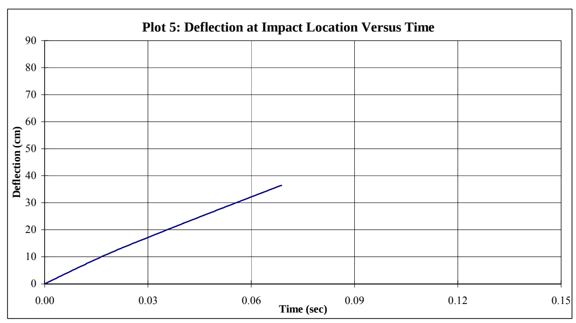
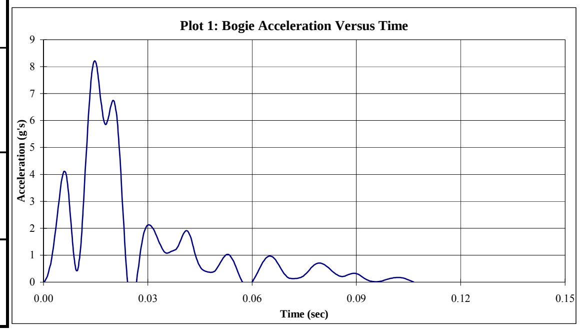


Figure 131. Results of Test No. DF-29

Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-30		
Test Date:	8-Aug-2005		
Failure Type:	0		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	184.2 mm Dia.	metric	7.25 in. Dia.
Post Length:	198.4 cm		(503.9 cm)
Embedment Depth:	101.6 cm		(258.1 cm)
Category:	HRD		
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	NA
Bogie Properties			
Impact Velocity:	5.9 m/s	(13.2 mph)	(19.4 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:		EDR-3	
Camera Data:	w-DV, AOS-1, AOS-2, and Photron		



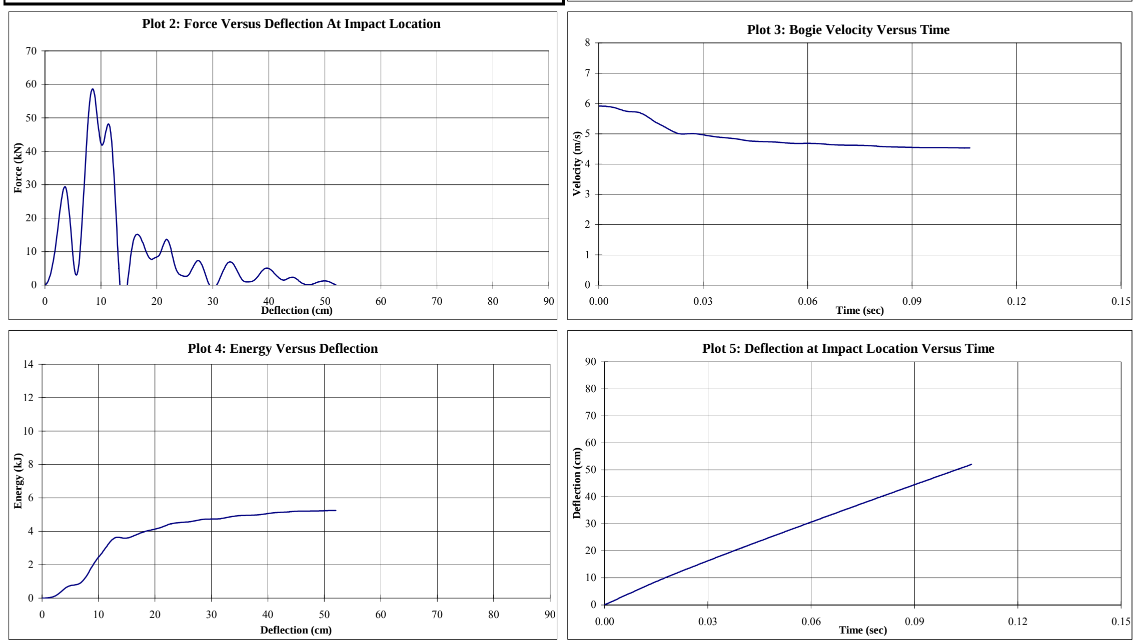


Figure 132. Results of Test No. DF-30

Appendix F. Post Size Determination – Excluding Inertial Effects

Intermediate Post Size Determination

Table 46 Douglas Fir Random Sample Testing Results – Excluding Inertia

Douglas Fir				
	Static Testing Results		Adjusted Dynamic Results	
Sample	Mean MOR (ksi)	Standard Deviation (ksi)	Mean MOR (ksi)	Standard Deviation (ksi)
Random Population Sample	8.10	1.07	9.72	1.28
Target Population Sample			10.04	1.21

Table 47. Ponderosa Pine Random Sample Testing Results – Excluding Inertia

Ponderosa Pine				
	Static Testing Results		Adjusted Dynamic Results	
Sample	Mean MOR (ksi)	Standard Deviation (ksi)	Mean MOR (ksi)	Standard Deviation (ksi)
Random Population Sample	5.95	1.33	7.70	1.73
Target Population Sample			7.85	1.84

Table 48. Minimum Diameter Calculation – Excluding Inertia

	Douglas Fir		**Ponderosa Pine**	
	Mpa	**(ksi)**	**Mpa**	**(ksi)**
Mean MOR	69.22	(10.04)	54.12	(7.85)
Standard Deviation	8.55	(1.24)	12.69	(1.84)
40% MOR	67.09	(9.73)	50.88	(7.38)
Minimum Diameter	160 mm	(6.27 in.)	175 mm	(6.88 in.)

Douglas Fir:

- $171\,\text{mm}\,{}^{+19\,\text{mm}}_{-6\,\text{mm}} \quad \left(6.75\,\text{in.}\,{}^{+0.75\,\text{in.}}_{-0.25\,\text{in.}}\right)$

Ponderosa Pine:

- $184\,\text{mm}\,{}^{+19\,\text{mm}}_{-6\,\text{mm}} \quad \left(7.25\,\text{in.}\,{}^{+0.75\,\text{in.}}_{-0.25\,\text{in.}}\right)$

The probability of failure for the 165-mm (6.5-in.) Douglas Fir posts was just under 15 percent, 25 percent lower than desired. With the 165-mm (6.5-in.) diameter Douglas Fir posts, the probability of system failure was less than 0.1 percent. For Ponderosa Pine, the probability of failure remained the same as presented in Chapter 11.

Re-Evaluation of Post Size

With the increased peak force and modified pressure distribution determined in Chapter 12, the probability method returned minimum diameter values of 198 mm (7.78 in.) for Ponderosa Pine and 176 mm (6.91 in.) for Douglas Fir. Rounding to the next highest quarter inch, the acceptable ranges of post sizes were determined as follows.

Ponderosa Pine:

$$210\,\text{mm}\,{}^{+19\,\text{mm}}_{-6\,\text{mm}} \quad \left(8.25\,\text{in.}\,{}^{+0.75\,\text{in.}}_{-0.25\,\text{in.}}\right)$$

Douglas Fir:

$$184\,\text{mm}\,{}^{+19\,\text{mm}}_{-6\,\text{mm}} \quad \left(7.25\,\text{in.}\,{}^{+0.75\,\text{in.}}_{-0.25\,\text{in.}}\right)$$

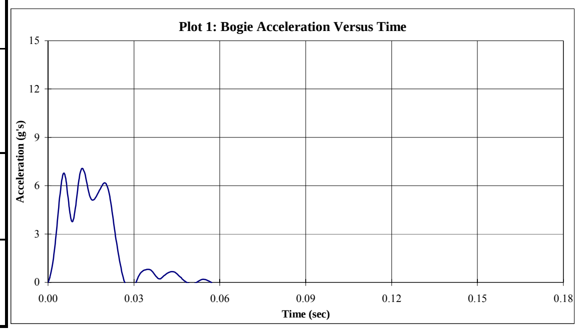
Monte Carlo simulation was utilized, as in Chapter 14, to simulate a 1,000 sample population of Ponderosa Pine posts based on the indicated size and strength distributions. Final results for Douglas Fir did not change and therefore were not simulated.

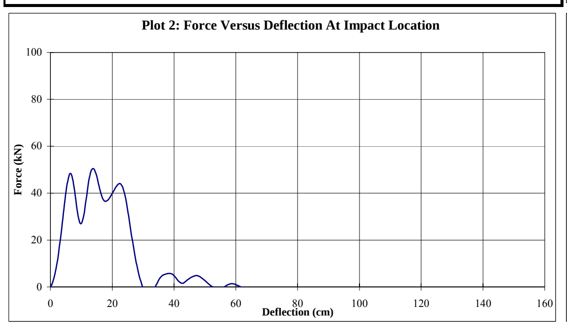
For the 210-mm (8.25-in.) target diameter, Ponderosa Pine had an average peak force of 16.2 kips with a standard deviation of 4.3 kips. For the 216-mm (8.5-in.) mid-range diameter, Ponderosa Pine averaged 18.2 kips of force with a standard deviation of 4.6 kips. The probability of post failure was 22 percent for the target diameter and 13 percent for the mid-range diameter, making the probability of system failure less than a quarter of a percent.

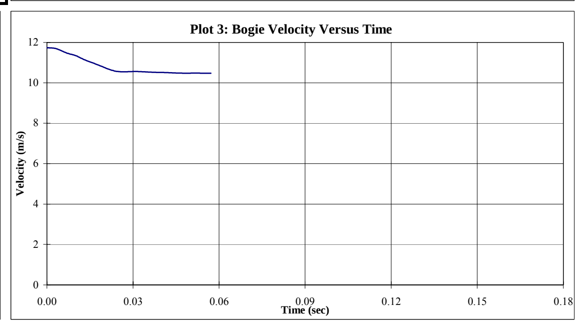
Appendix G. Soil Bogie Test Results

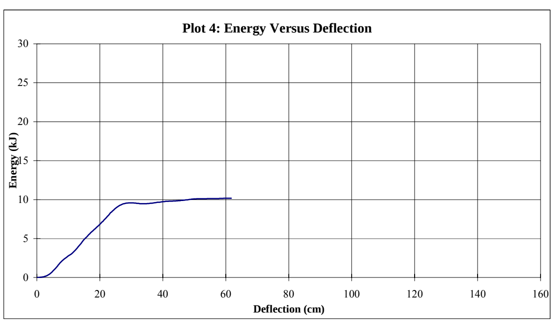
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-31		
Test Date:	16-Sep-2005		
Failure Type:	Post Fractured		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	183.9 mm Dia.	metric	7.24 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343	kg/m^3	(5493 pcf)
Bogie Properties			
Impact Velocity:	11.7 m/s	(26.2 mph)	(38.5 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









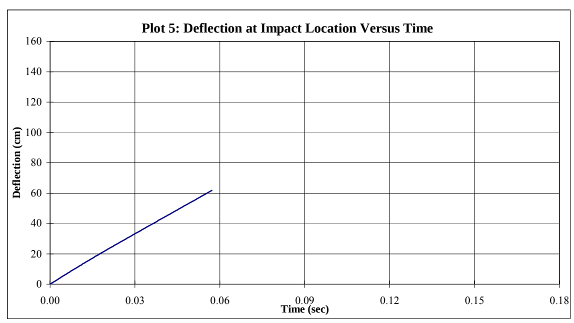
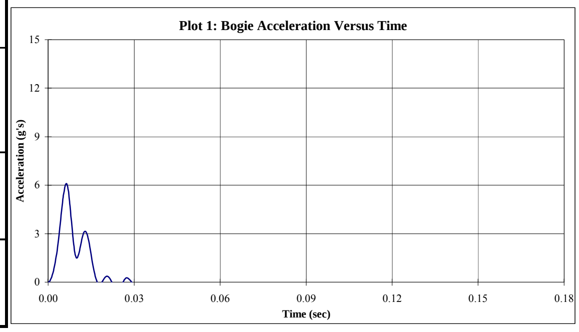
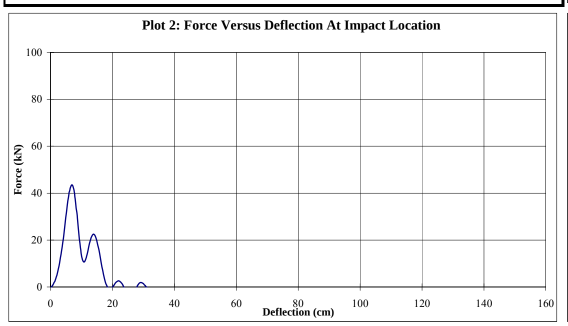


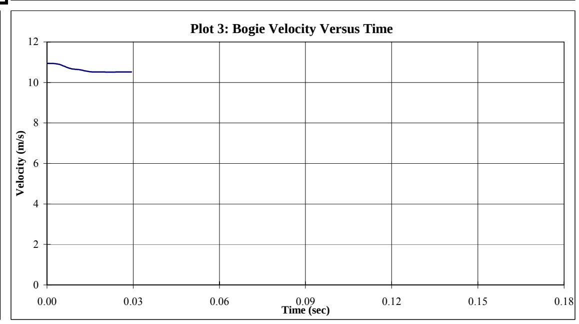
Figure 133. Results of Test No. PP-31

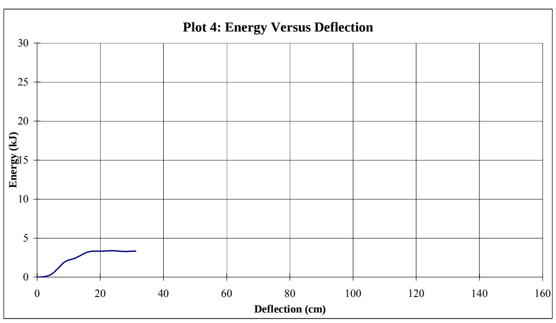
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-32		
Test Date:	19-Sep-2005		
Failure Type:	Post Fractured		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	184.9 mm Dia.	metric	7.28 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343	kg/m^3	(5493 pcf)
Bogie Properties			
Impact Velocity:	10.9 m/s	(24.5 mph)	(35.9 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









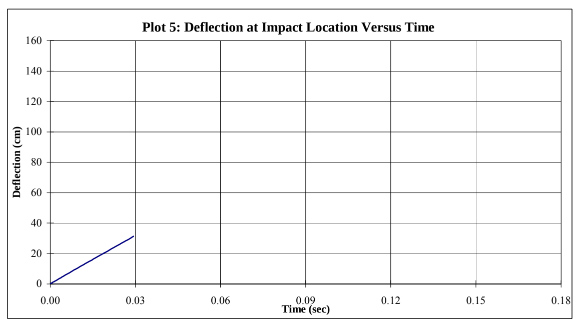
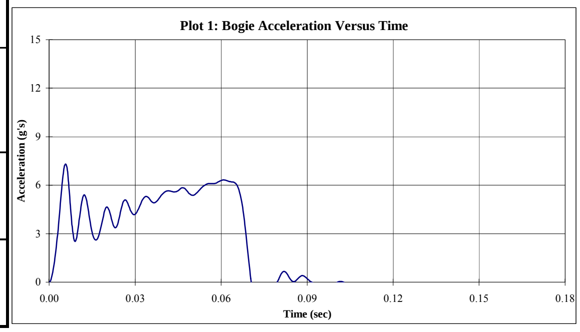
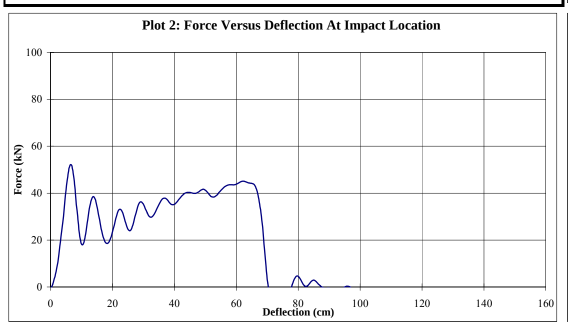


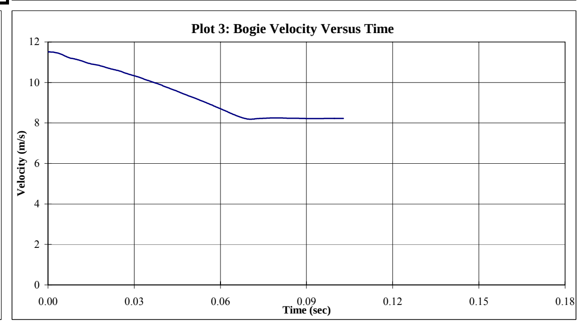
Figure 134. Results of Test No. PP-32

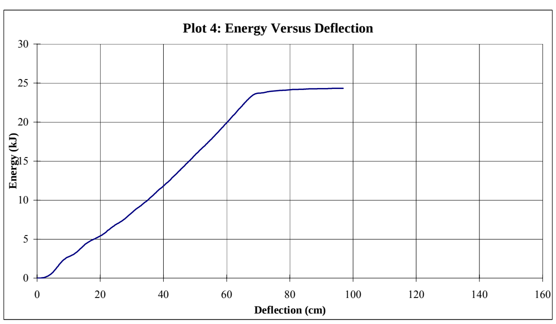
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	PP-33	
Test Date:	29-Sep-2005	
Failure Type:	Post Fractured	
Post Properties		
Post Type:	Southern Yellow Pine - Round Wooden	
Post Size:	185.9 mm Dia. metric	7.32 in. Dia.
Post Length:	198.1 cm	(503.2 cm)
Embedment Depth:	94.0 cm	(238.7 cm)
Category:	NA	
Soil Properties		
Gradation:	NCHRP 350 Grade B	
Moisture Content:	NA	
Compaction Method:	Air Tamped	
Soil Density, γ_d:	343 kg/m^3	(5493 pcf)
Bogie Properties		
Impact Velocity:	11.5 m/s (25.7 mph)	(37.7 fps)
Impact Location:	63.2 cm (24.9 in)	above groundline
Bogie Mass:	728 kg (1605 lbf)	
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV, AOS-1, AOS-3C	









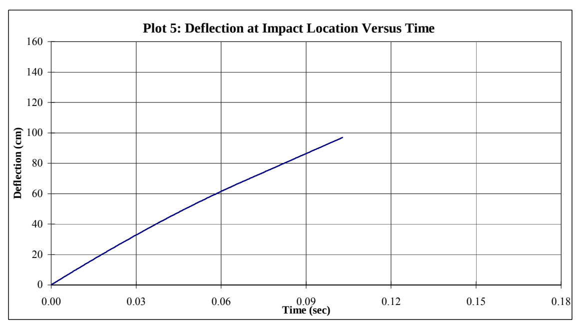
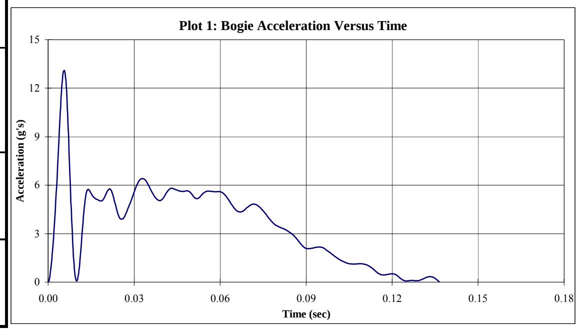
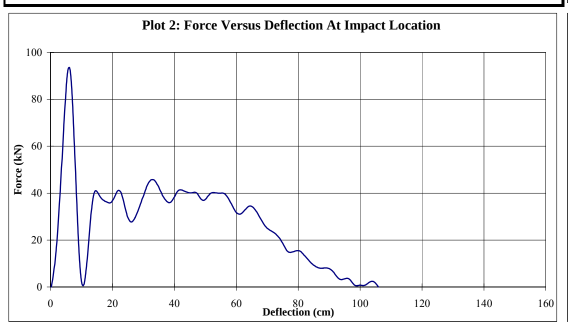


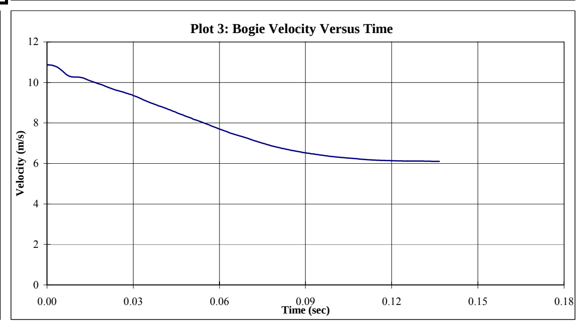
Figure 135. Results of Test No. PP-33

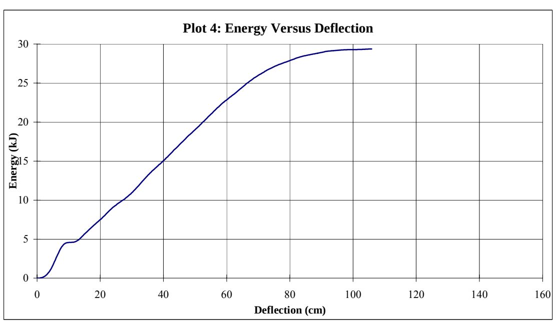
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	PP-34	
Test Date:	7-Nov-2005	
Failure Type:	Soil Failure	
Post Properties		
Post Type:	Ponderosa Pine - Round Wooden	
Post Size:	202.4 mm Dia. metric	7.97 in. Dia.
Post Length:	198.1 cm	(503.2 cm)
Embedment Depth:	94.0 cm	(238.7 cm)
Category:	NA	
Soil Properties		
Gradation:	NCHRP 350 Grade B	
Moisture Content:	NA	
Compaction Method:	Air Tamped	
Soil Density, γ_d:	343 kg/m^3	(5493 pcf)
Bogie Properties		
Impact Velocity:	10.9 m/s (24.3 mph)	(35.6 fps)
Impact Location:	63.2 cm (24.9 in)	above groundline
Bogie Mass:	728 kg (1605 lbf)	
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV, AOS-1, AOS-3C	









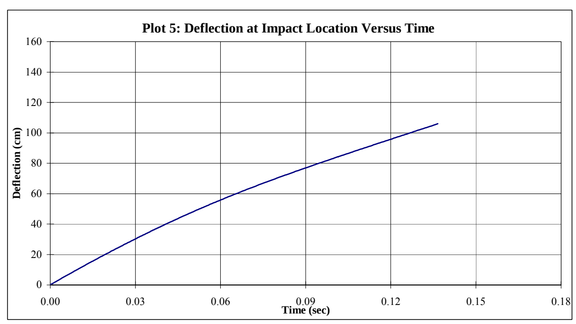
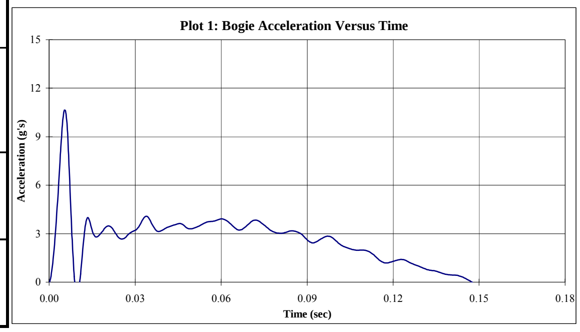
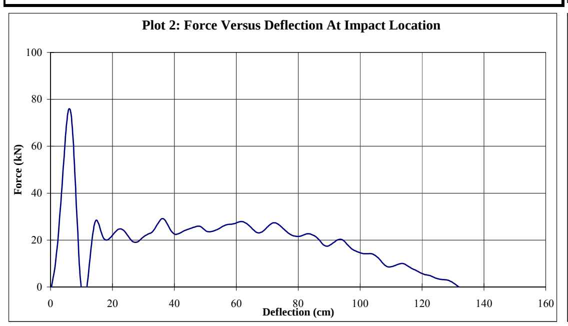


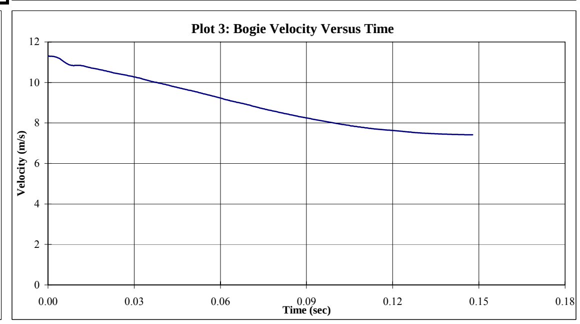
Figure 136. Results of Test No. PP-34

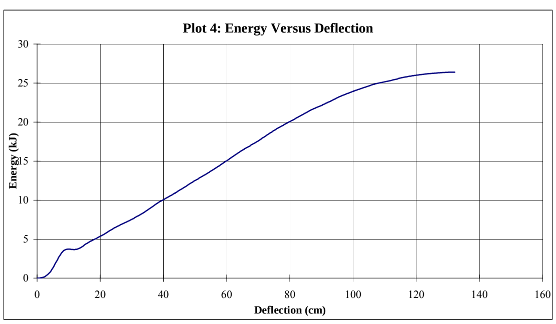
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	PP-35		
Test Date:	7-Nov-2005		
Failure Type:	Soil Failure		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	200.7 mm Dia.	metric	7.9 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	94.0	cm	(238.7 cm)
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343	kg/m^3	(5493 pcf)
Bogie Properties			
Impact Velocity:	11.3 m/s	(25.3 mph)	(37.1 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









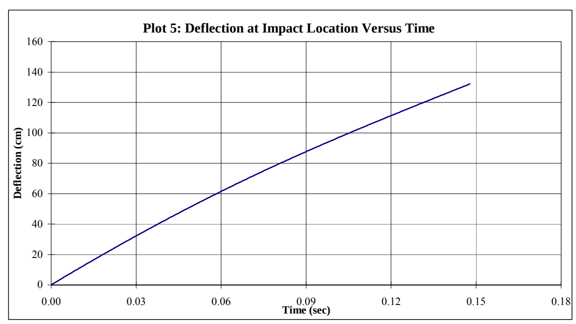
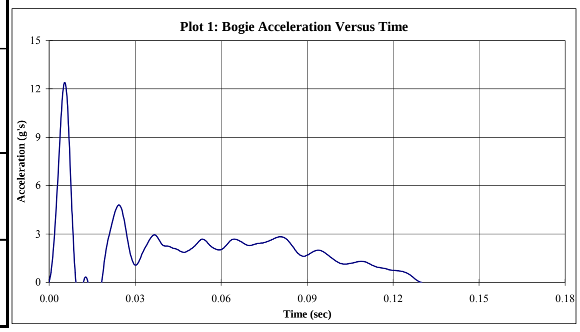


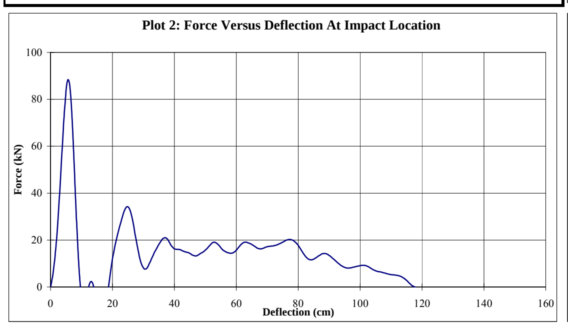
Figure 137. Results of Test No. PP-35

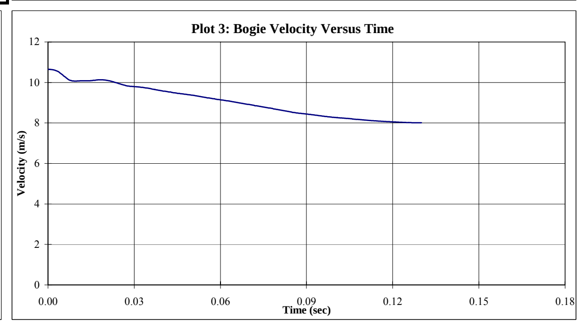
Midwest Roadside Safety Facility

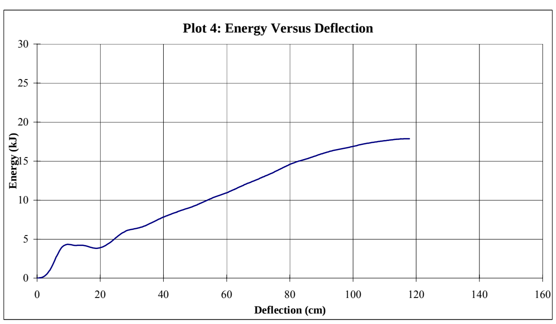
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	PP-36		
Test Date:	7-Nov-2005		
Failure Type:	Soil Failure		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	199.1 mm Dia.	metric	7.84 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	94.0	cm	(238.7 cm)
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343	kg/m^3	(5493 pcf)
Bogie Properties			
Impact Velocity:	10.6 m/s	(23.8 mph)	(34.9 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









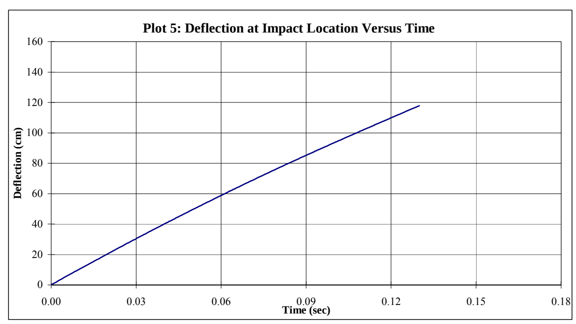
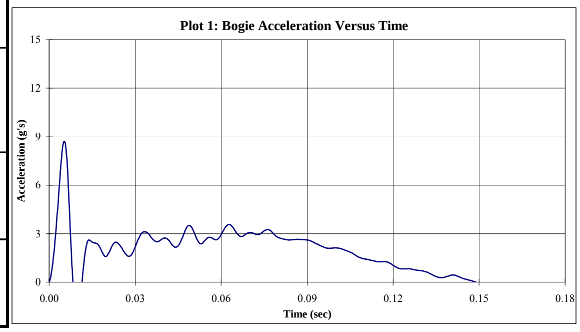
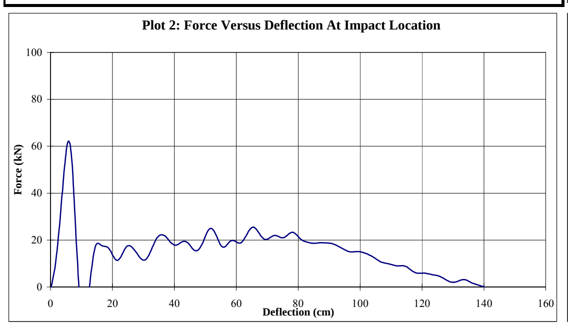


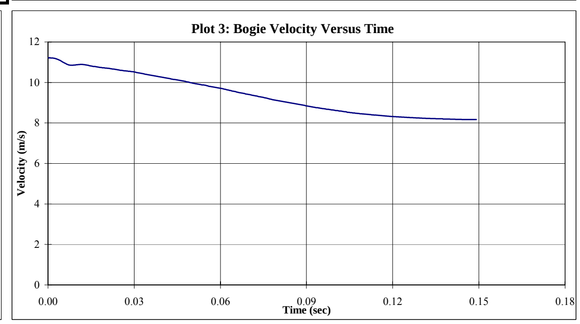
Figure 138. Results of Test No. PP-36

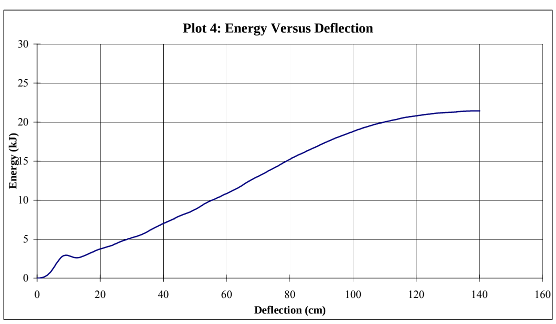
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	PP-37	
Test Date:	7-Nov-2005	
Failure Type:	Soil Failure	
Post Properties		
Post Type:	Ponderosa Pine - Round Wooden	
Post Size:	194.1 mm Dia. metric	7.64 in. Dia.
Post Length:	198.1 cm	(503.2 cm)
Embedment Depth:	94.0 cm	(238.7 cm)
Category:	NA	
Soil Properties		
Gradation:	NCHRP 350 Grade B	
Moisture Content:	NA	
Compaction Method:	Air Tamped	
Soil Density, γ_d:	343 kg/m^3	(5493 pcf)
Bogie Properties		
Impact Velocity:	11.2 m/s	(25.1 mph) (36.8 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV, AOS-1, AOS-3C	









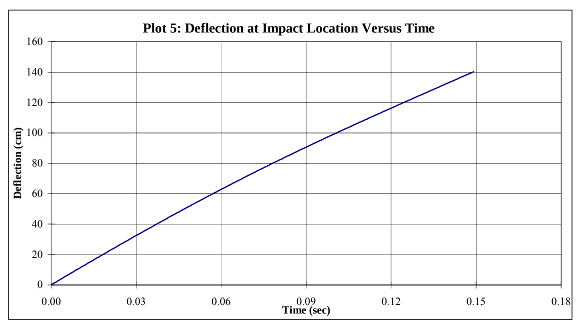
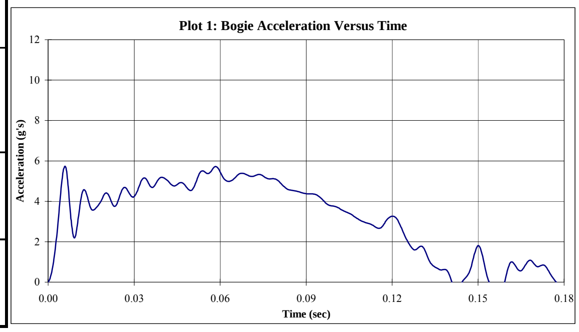


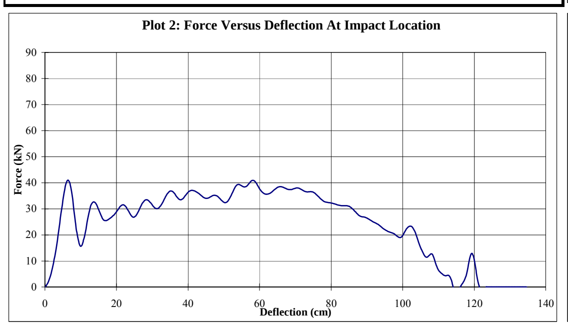
Figure 139. Results of Test No. PP-37

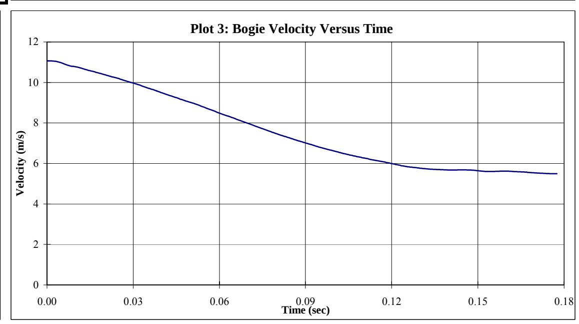
Midwest Roadside Safety Facility

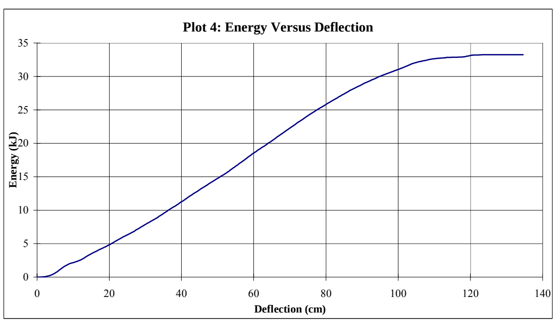
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-31		
Test Date:	19-Sep-2005		
Failure Type:	Soil Failure		
Post Properties			
Post Type:	Southern Yellow Pine - Round Wooden		
Post Size:	165.6 mm Dia. metric	6.52 in. Dia.	
Post Length:	198.1 cm	(503.2 cm)	
Embedment Depth:	101.6 cm	(258.1 cm)	
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343 kg/m^3	(5493 pcf)	
Bogie Properties			
Impact Velocity:	11.1 m/s	(24.8 mph)	(36.3 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









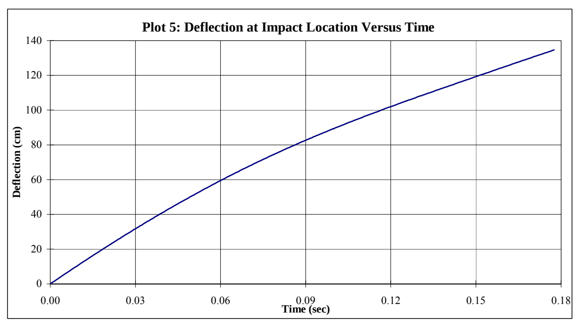
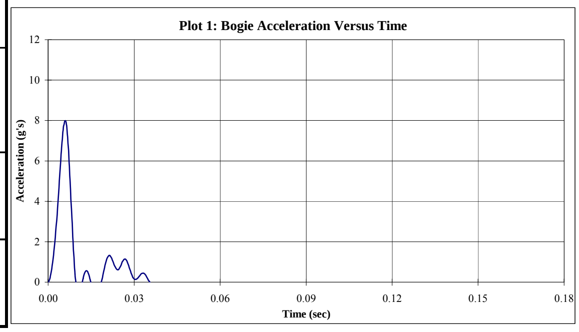
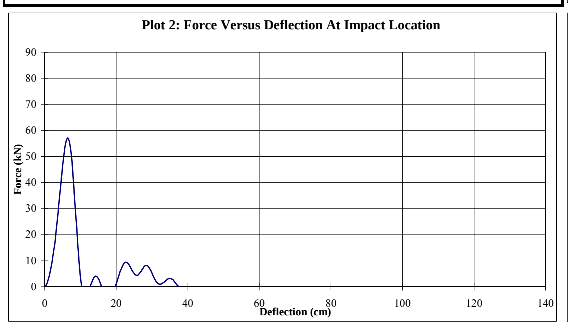


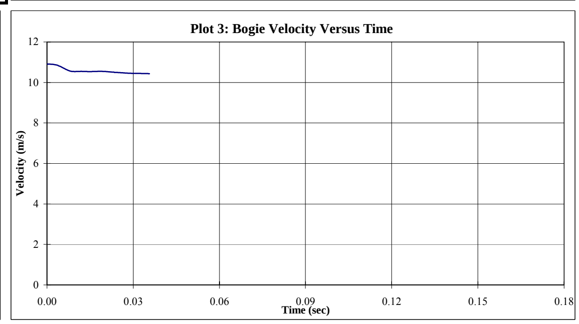
Figure 140. Results of Test No. DF-31

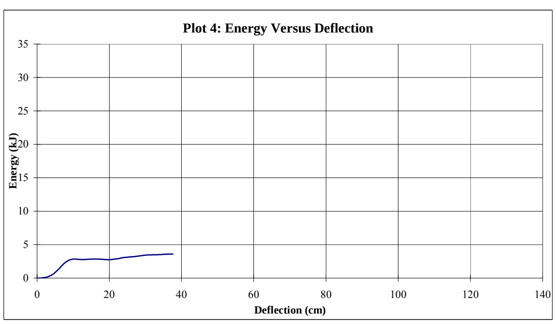
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-32		
Test Date:	19-Sep-2005		
Failure Type:	Post Fractured		
Post Properties			
Post Type:	Ponderosa Pine - Round Wooden		
Post Size:	165.6 mm Dia.	metric	6.52 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	101.6	cm	(258.1 cm)
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343	kg/m^3	(5493 pcf)
Bogie Properties			
Impact Velocity:	10.9 m/s	(24.4 mph)	(35.8 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









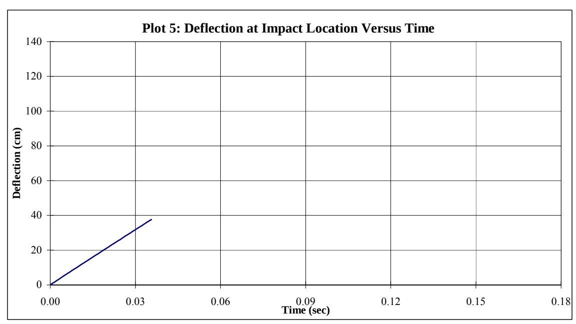
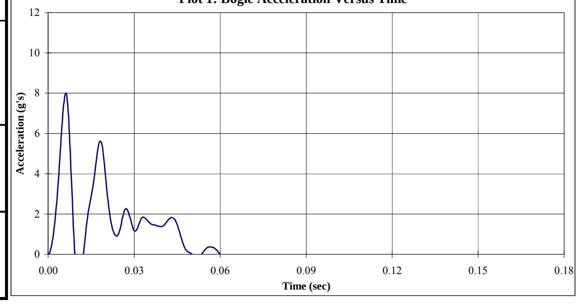


Figure 141. Results of Test No. DF-32

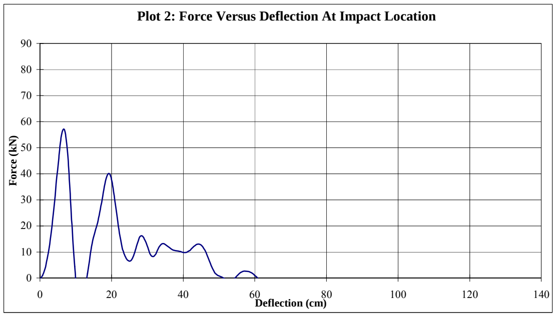
Midwest Roadside Safety Facility

Bogie Test Summary		
Test Information	CL Bogie MGS Height	
Test Number:	DF-33	
Test Date:	23-Sep-2005	
Failure Type:	Post Fractured	
Post Properties		
Post Type:	Southern Yellow Pine - Round Wooden	
Post Size:	168.3 mm Dia. metric	6.625 in. Dia.
Post Length:	198.1 cm	(503.2 cm)
Embedment Depth:	94.0 cm	(238.7 cm)
Category:	NA	
Soil Properties		
Gradation:	NCHRP 350 Grade B	
Moisture Content:	NA	
Compaction Method:	Air Tamped	
Soil Density, γ_d:	343 kg/m³	(5493 pcf)
Bogie Properties		
Impact Velocity:	10.8 m/s	(24.2 mph) (35.5 fps)
Impact Location:	63.2 cm	(24.9 in) above groundline
Bogie Mass:	728 kg	(1605 lbf)
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV, AOS-1, AOS-3C	

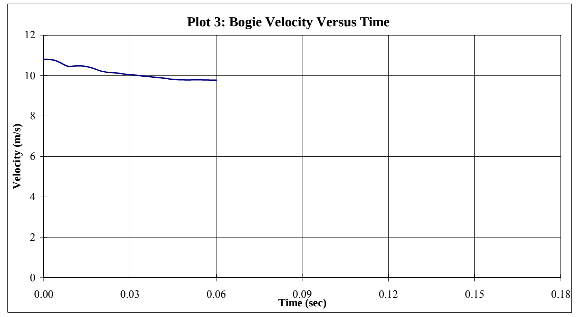
Plot 1: Bogie Acceleration Versus Time



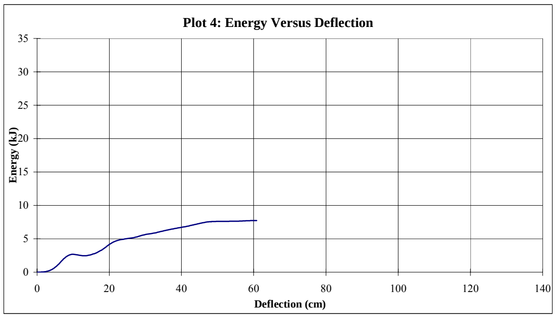
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection



Plot 5: Deflection at Impact Location Versus Time

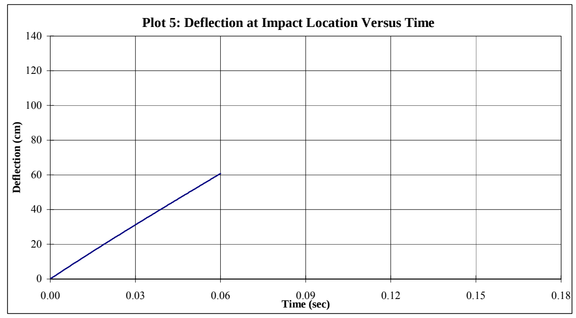
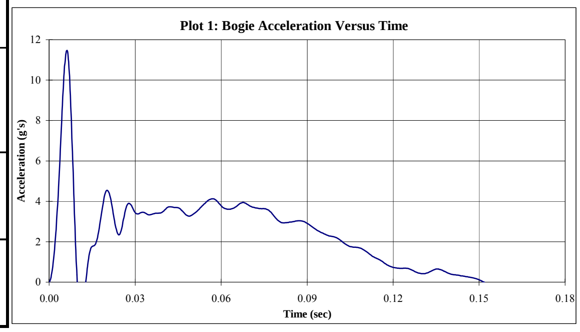
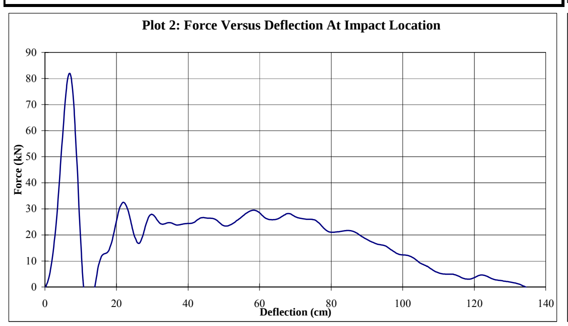


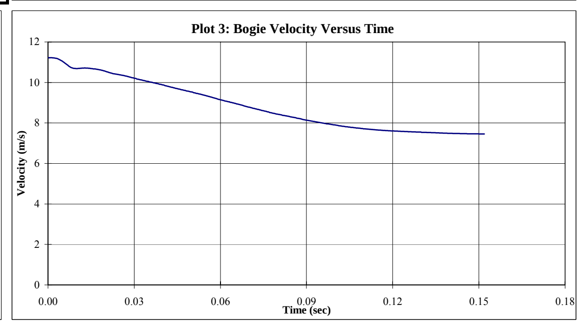
Figure 142. Results of Test No. DF-33

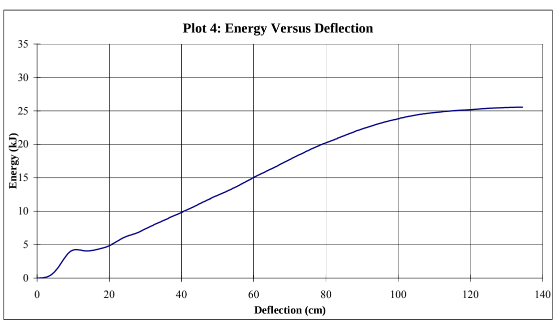
Midwest Roadside Safety Facility

Bogie Test Summary			
Test Information	CL Bogie MGS Height		
Test Number:	DF-34		
Test Date:	4-Oct-2005		
Failure Type:	Soil Failure		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	181.86 mm Dia. metric	7.16 in. Dia.	
Post Length:	198.1 cm	(503.2 cm)	
Embedment Depth:	94.0 cm	(238.7 cm)	
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343 kg/m^3	(5493 pcf)	
Bogie Properties			
Impact Velocity:	11.2 m/s	(25.1 mph)	(36.8 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









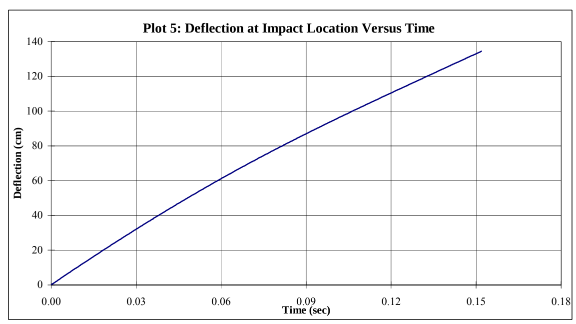
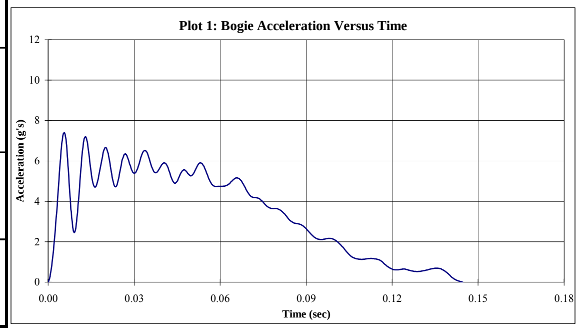


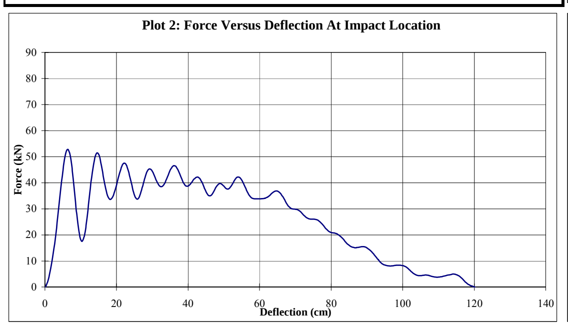
Figure 143. Results of Test No. DF-34

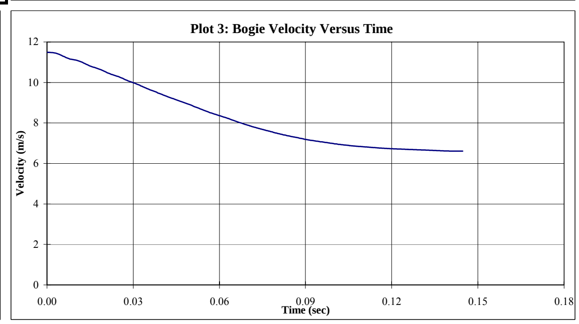
Midwest Roadside Safety Facility

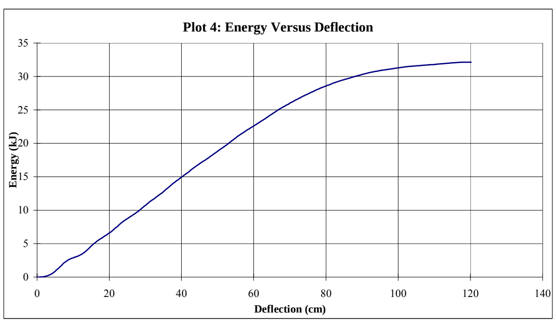
Bogie Test Summary

Test Information	CL Bogie MGS Height		
Test Number:	DF-35		
Test Date:	5-Oct-2005		
Failure Type:	Soil Failure		
Post Properties			
Post Type:	Douglas Fir - Round Wooden		
Post Size:	180.34 mm Dia.	metric	7.1 in. Dia.
Post Length:	198.1	cm	(503.2 cm)
Embedment Depth:	94.0	cm	(238.7 cm)
Category:	NA		
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	343	kg/m^3	(5493 pcf)
Bogie Properties			
Impact Velocity:	11.5 m/s	(25.7 mph)	(37.7 fps)
Impact Location:	63.2 cm	(24.9 in)	above groundline
Bogie Mass:	728 kg	(1605 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-DV, AOS-1, AOS-3C		









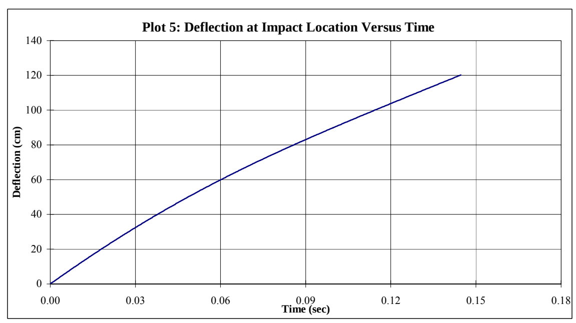
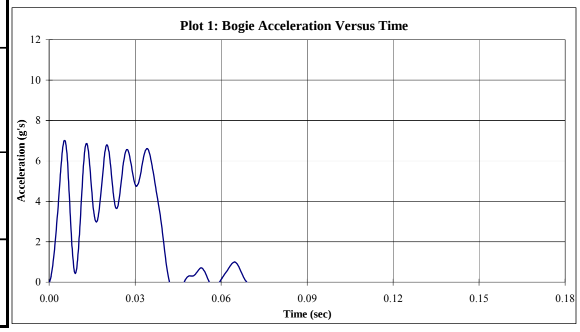


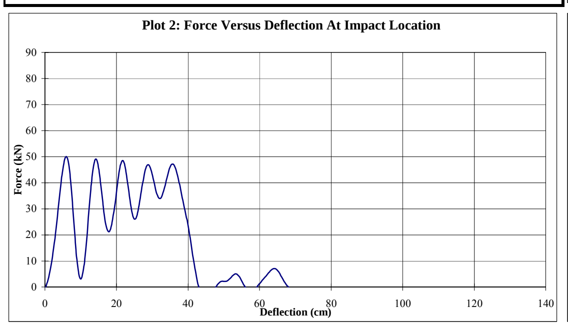
Figure 144. Results of Test No. DF-35

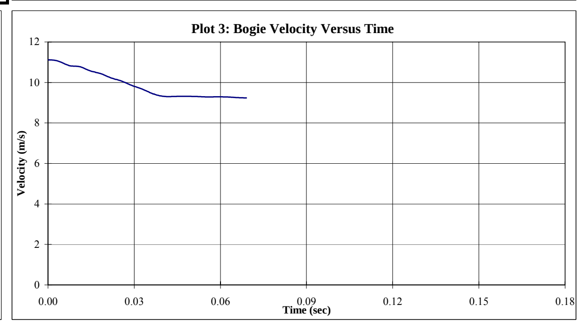
Midwest Roadside Safety Facility

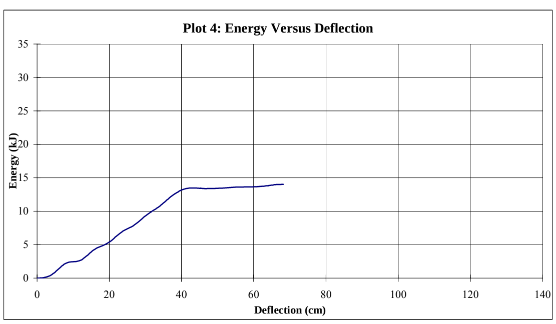
Bogie Test Summary

Test Information	CL Bogie MGS Height	
Test Number:	DF-36	
Test Date:	5-Oct-2005	
Failure Type:	Post Fractured	
Post Properties		
Post Type:	Douglas Fir - Round Wooden	
Post Size:	175.26 mm Dia. metric	6.9 in. Dia.
Post Length:	198.1 cm	(503.2 cm)
Embedment Depth:	94.0 cm	(238.7 cm)
Category:	NA	
Soil Properties		
Gradation:	NCHRP 350 Grade B	
Moisture Content:	NA	
Compaction Method:	Air Tamped	
Soil Density, γ_d:	343 kg/m^3	(5493 pcf)
Bogie Properties		
Impact Velocity:	11.1 m/s (24.9 mph)	(36.5 fps)
Impact Location:	63.2 cm (24.9 in)	above groundline
Bogie Mass:	728 kg (1605 lbf)	
Data Acquired		
Accelerometer Data:	EDR-3	
Camera Data:	Side View-DV, AOS-1, AOS-3C	









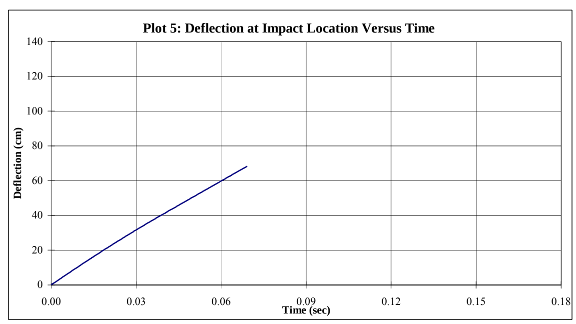


Figure 145. Results of Test No. DF-36

Appendix H. General Post Grading Criteria

All posts shall meet the current quality requirements of the American National Standards Institute (ANSI) 05.1, "Wood Poles" except as supplemented herein:

Manufacture:

All posts shall be smooth shaved by machine. No "ringing" of the posts, as caused by improperly adjusted peeling machine, is permitted. All outer and inner bark shall be removed during the shaving process. All knots and knobs shall be trimmed smooth and flush with the surface of the posts. The guardrail posts will be a minimum of 1.75-m (69-in.) long. The use of peeler cores is prohibited.

Ground-line:

The ground-line, for the purpose of applying these restrictions of ANSI 05.1 that reference the ground-line, shall be defined as being located 914-mm (36-in.) from the butt end of each post.

Size:

The size of the posts shall be classified based on their diameter at the ground-line and their length and will be species specific. The ground-line diameter shall be specified by diameter in 6-mm (¼-in.) breaks. The length shall be specified in 300-mm (1-ft) breaks. Dimension shall apply to fully seasoned posts. When measured between their extreme ends, the post shall be no shorter than the specified lengths but may be up to 75-mm (3-in.) longer.

Scars:

Scars are permitted in the middle third as defined in ANSI 05.1 provided that the depth of the trimmed scar is not more than (1 in.).

Shape and Straightness:

All timber posts shall be nominally round in cross section. A straight line drawn from the centerline of the top to the center of the butt of any post shall not deviate from the centerline of the post more than 32 mm (1 ¼ in.) at any point. Posts shall be free from reverse bends.

Splits and Shakes:

Splits or ring shakes are not permitted in the top two thirds of the post. Splits not to exceed the diameter in length are permitted in the bottom third of the post. A single shake is permitted in the bottom third, provided it is not wider than one-half the butt diameter.

Decay:

Allowed in knots only.

Holes:

Pin holes 1-mm (1/16-in.) or less are not restricted.

Slope of Grain:

1 in 10.

Compression Wood:

Not allowed, in the outer 25-mm (1-in.) or if exceeding ¼ of the radius.

Timber Spacers:

When timber spacers are required, the timber species shall be the same as those furnished for the timber posts. The size and hole location shall be as shown on the plans, with a tolerance of 6-mm (¼-in.), Spacers shall be of medium grain, at least four (4) rings per inch on one end, and free from splits, shakes, compression wood or decay in any form. Individual knots, knot clusters or knots in the same cross section of a face are permitted, provided they are sound or firm, and are limited in cumulative width (when measured between lines parallel to the edges) to no more than one-half the width of the face. Wane or the absence of wood is limited to one-third of the face on no more than 10 percent of the lot. Slope of grain deviation is limited to one in six. The material may be rough sawn or surfaced, full size, hit or miss, with a tolerance of 6-mm (¼-in.) for all dimensions.

Treatment:

Treating - American Wood-Preservers' Association (AWPA) – Book of Standards (BOS) U1-05 use category system UCS: user specification for treated wood; commodity specification B; Posts; Wood for Highway Construction must be met using the methods outlined in AWPA BOS T1-05 Section 8.2.

Each post treated shall have a minimum sapwood depth of 19 mm (3/4 in.) as determined by examination of the tops and butts of each post. Material that has been air dried or kiln dried shall be inspected for moisture content in accordance with AWPA standard M2 prior to treatment. Tests of representative pieces shall be conducted. The lot shall be considered acceptable when the average moisture content does not exceed 25 percent. Pieces exceeding 29 percent moisture content shall be rejected and removed from the lot.