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PHASE I PONDEROSA PINE ROUND POST EQUIVALENCY STUDY

Submitted by

Craig W. Price, B.S.M.E.
Former Undergraduate Research Assistant

Ronald K. Faller, Ph.D., P.E.
Research Associate Professor
MwRSF Director

Scott K. Rosenbaugh, M.S.C.E., E.I.T.
Research Associate Engineer

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

Bradley J. Winkelbauer, B.S.C.E.
Graduate Research Assistant

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Submitted to

FOREST PRODUCTS LABORATORY
Forest Service
U.S. Department of Agriculture
One Gifford Pinchot Drive
Madison, Wisconsin 53726-2398

ARIZONA LOG & TIMBERWORKS
1990 W. Central Ave
Eagar, Arizona 85925

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16. Abstract (Limit: 200 words)
The primary research objective was to determine the appropriate size and embedment depth of a round Ponderosa Pine (PP) post for serving as a surrogate for the standard 6-in. x 8-in. x 64-in. (152-mm x 203-mm x 1,626-mm) Southern Yellow Pine (SYP) post used in Arizona Department of Transportation (AzDOT) guardrail systems. A total of seventeen dynamic component tests were performed. Three baseline tests were conducted on 6-in. x 8-in. x 72-in. (152-mm x 203-mm x 1,829-mm) SYP posts with a 43¼-in. (1,099-mm) embedment depth for comparison with standard U.S. guardrail systems in a follow-on Phase II continuation effort. Three baseline tests were conducted on the standard 6-in. x 8-in. (152-mm x 203-mm) AzDOT SYP post at an embedment depth of 35 in. (889 mm). Eleven tests were conducted on round PP posts. The first three PP tests were conducted with a 37-in. (940-mm) embedment depth, and the remaining eight tests used a 35-in. (889-mm) embedment depth. The posts were fabricated with various targeted diameters: 8¼ in. (210 mm), 8½ in. (216 mm), and 8¾ in. (222 mm). The posts were embedded in a highly-compacted, coarse, crushed limestone material. For each test, acceleration data was used to determine the force vs. deflection and energy vs. deflection characteristics of the post-soil behavior. Post-soil interaction forces and energy dissipation characteristics of the PP posts were compared to those behaviors obtained for the SYP posts. From these comparisons, an 8½-in. (216-mm) diameter by 64-in. (1,626-mm) long graded PP post with an embedment depth of 35 in. (889 mm) provided similar post-soil behavior to that obtained for 6-in. x 8-in. x 64-in. (152-mm x 203-mm x 1,626-mm) SYP rectangular posts used by the AzDOT. Therefore, the AzDOT standard G4(2W) W-beam guardrail system would be expected to provide acceptable safety performance when configured with round PP posts with a minimum ground line diameter of 8½ in. (216 mm) as well as the current rectangular SYP posts.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in non-standard testing of roadside safety hardware as well as in standard full-scale crash testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Cody Stolle, Post-Doctoral Research Assistant.

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J.D. Reid, Ph.D., Professor
J.C. Holloway, M.S.C.E., E.I.T., Test Site Manager
R.W. Bielenberg, M.S.M.E., E.I.T., Research Associate Engineer
A.T. Russell, B.S.B.A., Shop Manager
K.L. Krenk, B.S.M.A, Maintenance Mechanic
D.S. Charroin, Laboratory Mechanic
S.M. Tighe, Laboratory Mechanic
Undergraduate and Graduate Research Assistants

Forest Products Laboratory
Michael A. Ritter, Assistant Director
David E. Kretschmann, Research General Engineer

Arizona Log & Timberworks
Randy Nicoll, Owner

Northern Arizona Wood Products Association (NAWPA)
Molly Pits, former Executive Director
Bill Greenwood, Executive Director

G K & J Communications
Jack Husted

Arizona Department of Transportation
Terry Otterness, P.E., Technical Support Engineer

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1 INTRODUCTION

1.1 Background

Over the last several decades, the southwestern U.S. experienced numerous forest fires, prompting a need for more preventive techniques. In 2000, President Bill Clinton initiated the creation of the National Fire Plan, which centered around four main goals: (1) improve prevention and suppression; (2) reduce hazardous fuels; (3) restore fire adapted ecosystems; and (4) promote community assistance [1].

Historically, fuel management has been a commonly-used technique for fire protection. In the 1960s, the U.S. Department of Agriculture (USDA) - Forest Service began managing fuels by using controlled-burn techniques, which are generally effective [2]. In order to remove the small-diameter forest thinnings (SDT) from a certain area, fires were started with containment. The thinnings, which could help fuel a fire in the future, consisted mostly of pine and fir species. However, due to both the lack of economic benefits and the high risk involved with controlled-burn methods, more cost-efficient methods were sought to remove the small-diameter forest thinnings.

Small diameter trees can be used in a variety of ways, including lumber, structural roundwood, wood composites, wood fiber products, compost, mulch, energy, and fuels [3]. By removing the potential fuel and selling it as various products, the cost of SDT removal would hopefully be recovered. Therefore, more uses for small diameter trees should be developed in order to increase the product potential [4]. Using SDT materials and in response to this need, researchers and engineers at the Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln (UNL), in cooperation with the Forest Products Laboratory (FPL), USDA - Forest Service, completed a study to determine the appropriate sizes of Southern Yellow Pine

(SYP), Douglas Fir (DF), and Ponderosa Pine (PP) round posts for use in the 31-in. (787-mm) tall, Midwest Guardrail System (MGS) [5].

In recent years, several unexpected forest fires also harmed large forests of PP timber in the State of Arizona. With such vast forests of affected timber, local producers within the timber industry deemed it necessary to further explore the use of PP material as posts in corrugated-beam guardrail systems. Unfortunately, no research had been performed to determine the appropriate size (diameter and length), required grading and strength, and embedment depth of PP posts for use in 28-in. (711 mm) and 27¾-in. (706 mm) high, W-beam guardrail systems with 35-in. and 43¼-in. embedment depths, which were utilized in Arizona and U.S. installations, respectively. Therefore, further research was necessary to determine the appropriate PP post dimensions for use as a surrogate post in common Arizona and U.S. guardrail systems.

It is common knowledge that longitudinal barriers, or guardrail systems, fulfill several functions along highways and roadways, including to: (1) safely contain and redirect errant vehicles and prevent impacts with hazardous fixed objects or geometric features and (2) dissipate an errant vehicle's kinetic energy without imparting excessive risk to the occupants. The safety performance of strong-post, W-beam guardrail systems is highly dependent on the post-soil behavior of vertical posts. For wood posts, the post-soil behavior is controlled by post size and strength, embedment depth, load height, and soil compaction. Wood posts should possess sufficient structural capacity, provide adequate lateral resistance, and exhibit reasonable energy dissipation characteristics during rotation in soil.

1.2 Objective

The primary research objective for this project was to determine the appropriate size and embedment depth for round PP posts in order to serve as a surrogate for standard 6-in. x 8-in.

(152-mm x 203-mm) SYP posts used in both Arizona and U.S. crashworthy W-beam guardrail systems. This component testing program was conducted to determine an alternative round wood post for use in existing guardrail systems that have met or been grandfathered under the impact safety standards published in the National Cooperative Highway Research Program (NCHRP) Report No. 350 [6]. In addition, the study would examine the post-soil behavior for PP round posts and SYP rectangular posts subjected to impact loading.

1.3 Scope

The research objective was achieved through the completion of several tasks. First, a literature review was conducted on the dynamic testing of rectangular and round wood posts placed in rigid and soil foundations in order to obtain information necessary to determine initial diameters and embedment depths for PP posts. After determining the initial dimensions, posts were acquired and selected for the testing and evaluation program. The post specimens were required to meet selected grading criterion based on the particular timber species. Seventeen dynamic component tests were conducted. Six tests were conducted on 6-in. x 8-in. (152-mm x 203-mm) SYP rectangular posts at two different embedment depths, 43¼ in. and 35 in. (1,099 mm and 889 mm). Three SYP posts had 64 in. (1,626 mm) lengths, while the three remaining SYP posts had 72 in. (1,829 mm) lengths. The remaining eleven tests were conducted on PP posts with various diameters and using both 35 and 37 in. (889 and 940 mm) embedment depths. The test results were analyzed, evaluated, and documented. Force versus displacement and energy versus displacement characteristics of the PP posts were compared to those obtained for SYP posts. Finally, conclusions and recommendations were made that pertain to the diameter, length, and embedment depth for round PP posts that provide comparable performance to SYP posts within Arizona Department of Transportation (AzDOT) standard W-beam guardrail systems.

A Phase II effort is underway to continue the investigation to determine the appropriate size and embedment depth of a round PP post for use as an alternative to 6-in. x 8-in. x 72-in. (152-mm x 203-mm x 1,829-mm) SYP posts used in metric-height, W-beam guardrail systems.

2 LITERATURE REVIEW

Numerous testing and evaluation studies have been performed on 6-in. x 8-in. (152-mm x 203-mm) SYP wood guardrail posts either embedded in soil or placed in rigid sleeve foundations. In 2007, Hascall et al. [5] reviewed and summarized previous post studies completed from 1960 through 2004. However, only a few prior research studies were available that involved the dynamic component testing of round PP wood guardrail posts in strong soil.

In 1978, Calcote et al. [7] conducted 80 pendulum tests to determine the effects of soil on the performance of guardrail posts. Steel and wood posts were tested in four different types of soil. The wood posts were 6-in. x 8-in. (152-mm x 203-mm) DF posts with a 35-in. (889-mm) embedment depth. For all strong-axis tests, the mode of failure was post rotation in the soil. The weak-axis tests generally experienced post fracture, with the exception of the tests using saturated clay soil.

Jeyapalan et al. [8] compared 7-in. (178-mm) diameter round SYP posts to W6x8.5 (W152x12.6) steel posts in 1984. In the study, two dynamic tests were conducted in both cohesive and non-cohesive soils. Of the two tests in each soil type, one test involved a steel post and the other test utilized a round wood post, both embedded 38 in. (965 mm) into the ground and impacted at a load height of 21 in. (533 mm). From these tests, the peak force and energy dissipated by the wood post in cohesive soil was found to be 16.3 kips (72.5 kN) and 326.4 kip-in. (36.9 kJ), respectively. Additionally, the total post deflection was 29 in. (737 mm). A comparison for the non-cohesive soil was unavailable due to almost instantaneous fracture of the wood post.

In 1988, Bronstad et al. [9] conducted a study involving bridge rail transitions. Twelve component tests were performed on both wood and steel posts embedded in a strong soil condition using a 4,000-lb (1,814-kg) pendulum at an impact height of 21 in. (533 mm). Wood posts were evaluated using four sizes – 6 in. x 8 in. (152 mm x 203 mm), 8 in. x 8 in. (203 mm x 203 mm), 10 in. x 10 in. (254 mm x 254 mm), and 12 in. x 12 in. (305 mm x 305 mm). Strong- and weak-axis testing was performed on the rectangular wood posts.

Holloway et al. [10] conducted a study in 1996 to evaluate increased post embedment for guardrail posts. A 50-in. (1,270-mm) embedment depth was examined and compared to the standard 44-in. (1,118-mm) embedment depth for both 6-in. x 8-in. (152-mm x 203-mm) Grade 2 SYP timber posts and W6x9 (W152x13.4) steel posts. For each type of post, four dynamic tests were conducted using a standard embedment depth, and one dynamic test was conducted using an extended embedment depth. After analyzing the results, it was noted that the additional 6 in. (152 mm) of embedment depth made little difference in the post-soil behavior. This conclusion was inconsistent with previous studies concerning post embedment depth, which may possibly be attributed to inconsistent soil compaction or a small sample size.

In 1998, MwRSF conducted a study to examine the dynamic properties of several types of posts installed on level terrain, where test results were later reported in various references [11-13]. Fourteen component tests were conducted on steel posts, while fifteen tests were conducted on wood posts of various dimensions. A bogie vehicle was used to impact the posts at 21.65 in. (550 mm) above the ground line and at a target speed of 20 mph (32 km/h). The results showed that wood posts produced a lower resistive force than steel posts and that a triangular soil pressure distribution most closely approximated the test data. Selected results from two tests involving 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts with an embedment depth of 43 in. (1,092 mm) are shown in Table 1.

Table 1. IBT Test Results for 6-in. x 8-in. (152-mm x 203-mm) SYP Wood Posts [11-12][a]

Test No.	Impact Velocity mph (km/h)	Peak Force		Average Force		Average Energy		Failure Type
		Force kips (kN)	Deflection in. (mm)	@ 10" kips (kN)	@ 15" kips (kN)	@ 10" kip-in. (kJ)	@ 15" kip-in. (kJ)	
IBT-14	20.0 (32.2)	19.4 (86.3)	3.9 (99)	14.8 (65.8)	16.1 (71.6)	148.0 (16.7)	241.5 (27.3)	Rotation in Soil
IBT-24	19.0 (30.6)	19.6 (87.2)	3.6 (91)	13.8 (61.4)	14.0 (62.3)	138.0 (15.6)	210.0 (23.7)	Rotation in Soil
Average	19.5 (31.3)	19.5 (86.7)	3.8 (95)	14.3 (63.6)	15.1 (67.2)	143.0 (16.2)	226.5 (25.6)	

[a] – Post embedment depth was 43 in. (1,092 mm), while load height was 21.65 in. (550 mm).

In 2007, Hascall et al. [5] conducted two dynamic tests on 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts at a 24⅞-in. (632-mm) impact height. The wood posts were embedded 37 in. (940 mm) and 40 in. (1,016 mm) into the soil for test nos. RWP-1 and RWP-2, respectively. Both tests used a strong soil conforming to American Association of State Highway and Transportation Officials (AASHTO) Grading B, while the posts were impacted by a bogie vehicle travelling at a target speed of 25 mph (40 km/h). The test results are summarized in Table 2.

Table 2. FPL Test Results for 6-in. x 8-in. (152-mm x 203-mm) Wood Posts [5][b]

Test No.	Impact Velocity mph (km/h)	Peak Force		Average Force @ 15" kips (kN)	Average Energy @ 15" kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
		Force kips (kN)	Deflection in. (mm)				
RWP-1	25.9 (41.7)	15.7 (69.7)	2.4 (61)	8.2 (36.5)	122.7 (13.9)	42.4 (1,076)	Rotation in Soil
RWP-2	25.2 (40.5)	14.1 (62.7)	15.9 (405)	10.7 (47.6)	160.5 (18.1)	38.4 (975)	Rotation in Soil
Average	25.6 (41.1)	14.9 (66.2)	9.2 (233)	9.4 (42.0)	141.0 (15.9)	40.4 (1,026)	

[b] – Post embedment depth was 37 and 40 in. (940 and 1,016 mm), while load height was 24⅞-in. (632-mm).

Additionally, 16 dynamic tests on round wood posts were conducted in strong soil conforming to AASHTO Grading B. Seven of the tests were conducted on PP posts, six were DF, and the remaining three were SYP, all with varying diameters. The tests used an embedment depth of 37 in. (940 mm), with the exception of two tests each from PP and DF, which were at 40 in. (1,016 mm). Peak force, average force, and average energy at 15 in. (381 mm) of deflection were calculated for all tests and are shown in Appendix A.

Forty-five tests were also conducted on the post installed in a rigid sleeve: 15 for DF, 15 for PP, and 15 for SYP. From these tests, the modulus of rupture (MOR) for each type of post was calculated, as well as peak forces and energy. The results from the PP tests are also shown in Appendix A. From the testing, it was noted that the PP calculated MOR was slightly lower than the MOR calculated for SYP.

In 2011, Homan et al. [14] conducted dynamic component testing to determine the post-soil behavior of steel and wood posts embedded in compacted soil. Of the 26 dynamic tests performed, two tests involved 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts installed on level terrain, two tests involved W6x16 (W152x23.8) steel posts placed on level terrain, and the remaining tests utilized a slope or were inconclusive. A compacted, coarse, crushed limestone material meeting Grading B of AASHTO M147-95 (1990) was utilized for all four level-terrain tests. The testing results for the 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts with an embedment depth of 40 in. (1,016 mm) and impacted 24⅞ in. (632 mm) above the ground line are shown in Table 3.

Table 3. MSE Wall Test Results for 6-in. x 8-in. (152-mm x 203-mm) SYP Wood Posts [14][c]

Test No.	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy		Maximum Deflection in. (mm)	Failure Type
		Force kips (kN)	Deflection in. (mm)	@ 15" kips (kN)	@ 20" kips (kN)	@ 15" kip-in. (kJ)	@ 20" kip-in. (kJ)		
GWB-14	19.3 (31.0)	14.6 (65.0)	2.9 (74)	11.6 (51.5)	10.5 (46.6)	174.0 (19.7)	210.0 (23.7)	31.7 (805)	Rotation in Soil
GWB-15	19.6 (31.6)	13.5 (60.2)	4.0 (102)	11.3 (50.5)	10.3 (45.8)	169.5 (19.2)	206.0 (23.3)	30.0 (761)	Rotation in Soil
Average	19.5 (31.3)	14.1 (62.6)	3.5 (88)	11.5 (51.0)	10.4 (46.2)	172.5 (19.5)	208.0 (23.5)	30.8 (783)	

[b] – Post embedment depth was 40 in. (1,016 mm), while load height was 24⅞-in. (632-mm).

3 INITIAL POST MATERIALS

3.1 Grading

All timber post materials were provided by Arizona Log & TimberWorks. The rectangular SYP posts were purchased from an Arizona vendor and delivered to MwRSF, while the PP posts were manufactured by Arizona Log & TimberWorks and shipped to Lincoln, Nebraska in several installments. The material certification for the SYP and PP posts are provided in Appendix B. The SYP posts conformed to Grade 1 and complied with AzDOT requirements for timber guardrail posts and blocks, also shown in Appendix B. The PP posts were initially noted to comply with the general timber grading criteria that were developed for use in the MwRSF-FPL MGS post study [5]. The grading criteria for the initial shipment of round PP posts are provided for convenience in Appendix B. The criteria were specified to prevent damaged or poorly-processed products from being used in a guardrail system based on the parameters established for wood poles in the American National Standards Institute (ANSI) 05.1 [15]. Specific changes were made to the limits on manufacturing methods, scars, shape, straightness, splits, shakes, decay, holes, slope of grain, and compression wood.

3.2 Selection

Standard, 6-in. x 8-in. (152-mm x 203-mm) SYP posts are used in both AzDOT and U.S. strong-post, W-beam guardrail systems. The AzDOT standard specifications for a G4(2W) guardrail system corresponds to a W-beam rail height of 28 in. (711 mm), a post length of 64 in. (1,626 mm), and an embedment depth of 35 in. (889 mm), as shown in Appendix B. Following metrication, a common U.S. standard guardrail system was configured with a W-beam rail height of 27¾ in. (706 mm), a post length of 72 in. (1,829 mm), and an embedment depth of 43¼ in. (1,099 mm).

For the SYP materials, a total of 12 posts were provided. From this sample, three posts were selected for testing the U.S. standard wood post, while another three posts were selected for testing the AzDOT standard wood post.

The preliminary dimensions for PP posts were calculated based upon the previous dynamic testing of both SYP and PP wood posts [5, 8, 11-12]. For informational purposes only, test results from the prior FPL study are provided in Tables A-1 through A-3 of Appendix A for round PP posts and rectangular 6-in. x 8-in. (152-mm x 203-mm) SYP posts. However, it should be noted that the initial diameters and lengths for the PP round posts may change based on the results obtained from the rectangular SYP post testing performed within this study. Thus, 76 PP posts were obtained with various diameters and lengths, as shown in Appendix B. As later presented in detail within Chapter 6, the initial PP post diameter and length that was selected to meet the AzDOT standard was determined to be 8¼ in. (210 mm) diameter by 66 in. (1,676 mm) long. For the U.S. standard, the initial PP post size and length was determined to be 9½ in. (241 mm) diameter by 75 in. (1,905 mm) long.

4 TEST CONDITIONS

4.1 Test Facility

The test facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest from the University of Nebraska-Lincoln.

4.2 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie, onboard accelerometers, optical speed trap, high-speed and standard-speed digital video cameras, and a still camera.

4.2.1 Bogie

A rigid-frame bogie vehicle was used to impact the posts. An impact head, with a center height of 21.65 in. (550 mm), was used in the testing program. The impact head consisted of a steel pipe wrapped with a ¾-in. (19-mm) thick neoprene belting to prevent local damage to the post during the impact event. The bogie vehicle with impact head is shown in Figure 1. The bogie weight, including accelerometers, was 1,833 lb (831 kg) for test nos. AZSYP-1 through AZSYP-6, 1,873 lb (850 kg) for test nos. AZPP-1 through AZPP-3, 1,860 lb (844 kg) for test nos. AZPP-4 through AZPP-7, 1,871 lb (849 kg) for test nos. AZPP-8 and AZPP-9, and 1,857 lb (842 kg) for test nos. AZPP-10 and AZPP-11.

A pickup truck with a reverse cable tow system was used to propel the bogie to a target impact speed. When the bogie approached 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 brought safely to rest after the test.

Figure 1. Rigid-Frame Bogie Vehicle

4.2.2 Accelerometer

Two environmental shock and vibration sensor/recorder systems were mounted on the bogie vehicle near its center of gravity (c.g.) to measure the accelerations in the longitudinal, lateral, and vertical directions. However, only the longitudinal acceleration was processed and reported.

The first accelerometer system, SLICE 6DX, was a modular data acquisition system manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the body of the custom built SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data. The SLICE 6DX was used in all tests except for test nos. AZPP-8 and AZPP-9.

For test nos. AZPP-8 and AZPP-9, a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California was used instead of the SLICE 6DX. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by DTS of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second accelerometer system used in all tests, Model EDR-3, was a triaxial piezoresistive accelerometer system manufactured by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz low-pass filter. The "DynaMax 1 (DM-1)" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.2.3 Optic Speed Trap

A retroreflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Three retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the bogie vehicle which reflected the beam of light. When the emitted beam of light was returned to the Emitter/Receiver, a signal was sent to the Optic Control Box, which in turn sent a signal to the data computer as well as activated the External LED box. The computer recorded the signals at a sample rate of 10,000 Hz. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.2.4 Photography Cameras

One AOS X-PRI high-speed digital video camera and one JVC digital video camera were used to document each test. For test nos. AZSYP-1 through AZSYP-6, an additional JVC digital video camera was also used. For test nos. AZPP-10 and AZPP-11, two GoPro Hero 3 digital video cameras were also used. The AOS X-PRI high-speed camera, the JVC digital video cameras, and the GoPro Hero 3 digital video cameras had frame rates of 500 frames per second, 29.97 frames per second, and 120 frames per second, respectively. Cameras were placed laterally from the post with a view perpendicular to the bogie’s direction of travel. A Nikon D50 digital still camera was also used to document pre-test and post-test conditions for all tests.

4.3 End of Test Determination

When the impact head initially contacts the test article, the force exerted by the surrogate test vehicle is directly perpendicular. However, as the post rotates, the surrogate test vehicle’s orientation and path moves further from perpendicular. This introduces two sources of error: (1) the contact force between the impact head and the post has a vertical component and (2) the impact head slides upward along the test article. Therefore, only the initial portion of the accelerometer trace may be used since variations in the data become significant as the system rotates and the surrogate test vehicle overrides the system. For this reason, the end of the test needed to be defined.

Guidelines were established to define the end of test time using the high-speed video of the crash test. The first occurrence of any one of the following three events was used to determine the end of the test: (1) the test article fractures; (2) the surrogate vehicle overrides/loses contact with the test article; or (3) a maximum post rotation of 45 degrees.

4.4 Data Processing

The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [16]. The pertinent acceleration signal was extracted from the bulk of the data signals. 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 versus time. Initial velocity of the bogie, calculated from the optic speed trap data, was then used to determine the bogie velocity, and the calculated velocity trace was integrated to find the bogie's displacement. This displacement is also the displacement of the post. Combining the previous results, a force vs. deflection curve was plotted for each test. Finally, integration of the force vs. deflection curve provided the energy vs. deflection curve for each test.

4.5 Results

The desired information from the bogie tests was the post's resistive force against the bogie vehicle in relation to the post deflection as measured at the impact height. These results would then be used to determine the total energy (i.e., area under force versus deflection curve) dissipated during each test.

Although the acceleration data was applied to the impact location, the data came from the center of gravity of the rigid bogie. Error may be potentially induced to the data; since, the bogie may not be perfectly rigid and sustains vibrations. The bogie may rotate during impact events, causing differences in accelerations between the bogie's center of mass and the impact head. While these issues may potentially affect the data, the effects are believed to be very small for such short-duration events. Thus, the data was still deemed valid for comparative purposes. Filtering procedures were applied to the electronic data to smooth out vibrations. The rotations of the bogie were minor. One useful aspect of using accelerometer data was that it included inertial influences in post's resistive force. Mass effects were considered beneficial as they can affect barrier performance as well as influence test results. The accelerometer data for each test was processed in order to obtain acceleration, velocity, and deflection curves, as well as force versus deflection and energy versus deflection curves.

5 DYNAMIC TESTING – ROUND 1 - SYP POSTS

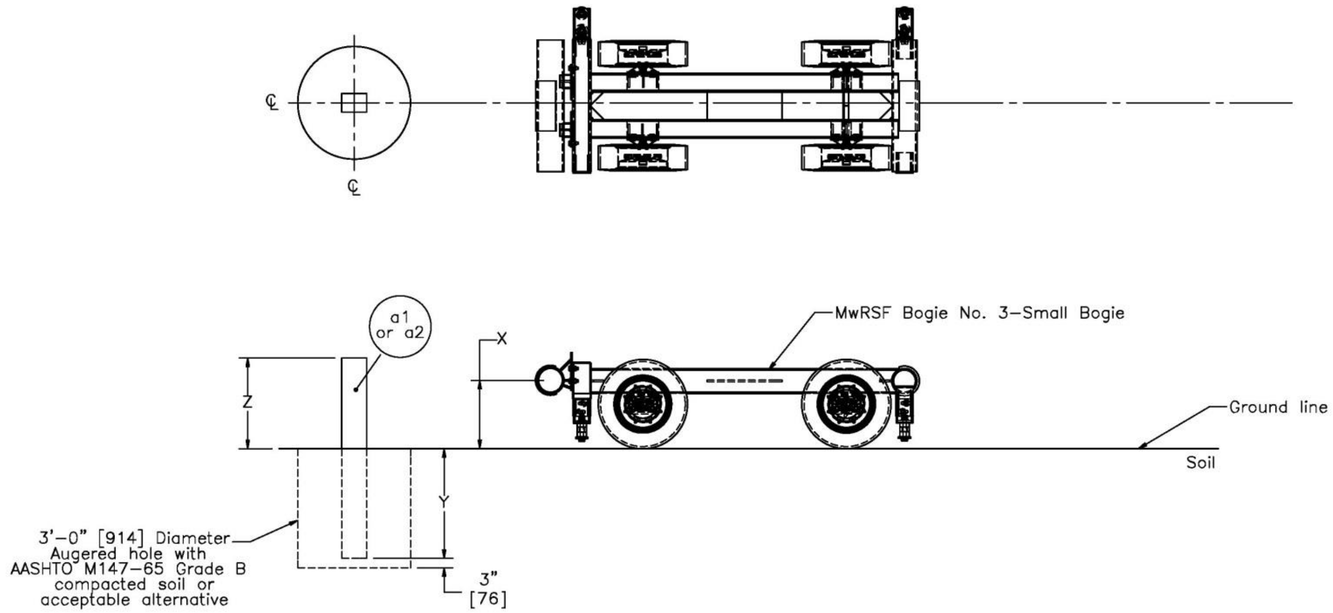
5.1 Purpose

MwRSF has previously conducted many dynamic bogie tests on 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts. However, only a fraction of these tests had been conducted with the posts embedded in strong soil on level terrain. Therefore, additional bogie tests were undertaken on both the 64-in. (1,626-mm) and 72-in. (1,829-mm) long SYP posts to determine their dynamic response in soil as well as to aid in the sizing (diameter and length) of the PP posts.

5.2 Scope

Six bogie tests were conducted on 6-in. x 8-in. (152-mm x 203-mm) SYP posts embedded in soil. In test nos. AZSYP-1 through AZSYP-3, a 72-in. (1,829-mm) long post was embedded to a depth of 43¼ in. (1,099 mm). In test nos. AZSYP-4 through AZSYP-6, a 64-in. (1,626-mm) long post was embedded to a depth of 35 in. (889 mm). A compacted, coarse, crushed limestone material, as recommended by MASH [17], was utilized for all component tests. The target impact conditions consisted of an impact speed of 20.0 mph (32.2 km/h) and an impact angle of 0 degrees, creating a classical "head-on" or full-frontal impact and strong-axis bending. Because the load heights for both the AzDOT and U.S. standards differed by less than ¼ in. (6 mm), the posts were impacted 21.65 in. (550 mm) above the ground line for all tests. This load application height corresponded to the center of metric-height, W-beam guardrail systems. The bogie testing matrix and test setup for the SYP rectangular posts are shown in Figures 2 through 3. Material specifications, mill certifications, and certificates of conformity for the rectangular SYP post material (test nos. AZSYP-1 through AZSYP-6) are provided in Appendix B.

Test Quantity	Post Species	Dimensions in. x in. [mm x mm]	Embedment Depth (Y) in. [mm]	Top of Post Height (Z) in. [mm]	Post Length in. [mm]	Load Height (X) in. [mm]	Bogie No.	Bogie Speed mph [km/h]
3	SYP	6x8 [152x203]	35 [889]	29 [737]	64 [1626]	21.65 [550]	3	20 [32.2]
3	SYP	6x8 [152x203]	43 1/4 [1099]	28 3/4 [730]	72 [1829]	21.65 [550]	3	20 [32.2]



Note: (1) For the load height of 21.65" [550], the rear bumper of the small bogie may be used as the impact head.

(2) It was desired that a load height of 21 7/8" [556] be used for the 64" [1626] long PP posts. For ease of testing, a 21.65" [550] load height can be used.

MwRSF Midwest Roadside Safety Facility	Ponderosa Pine Post Alternatives Southern Yellow Pine Test Setup	SHEET: 1 of 2 DATE: 6/17/2013 DRAWN BY: SDB
	DWG. NAME. PPROUND_R7	SCALE: 1:44 UNITS: in.[mm]
		REV. BY: KAL/RKF

Figure 2. Bogie Testing Matrix and Setup – SYP Posts (Round 1)

Item No.	QTY.	Description	Material Specification	Hardware
a1	3	6"x8"x64" [152x203x1626] Southern Yellow Pine Post	SYP Grade No. 1 or better	PDE01
a2	3	6"x8"x72" [152x203x1829] Southern Yellow Pine Post	SYP Grade No. 1 or better	PDE02

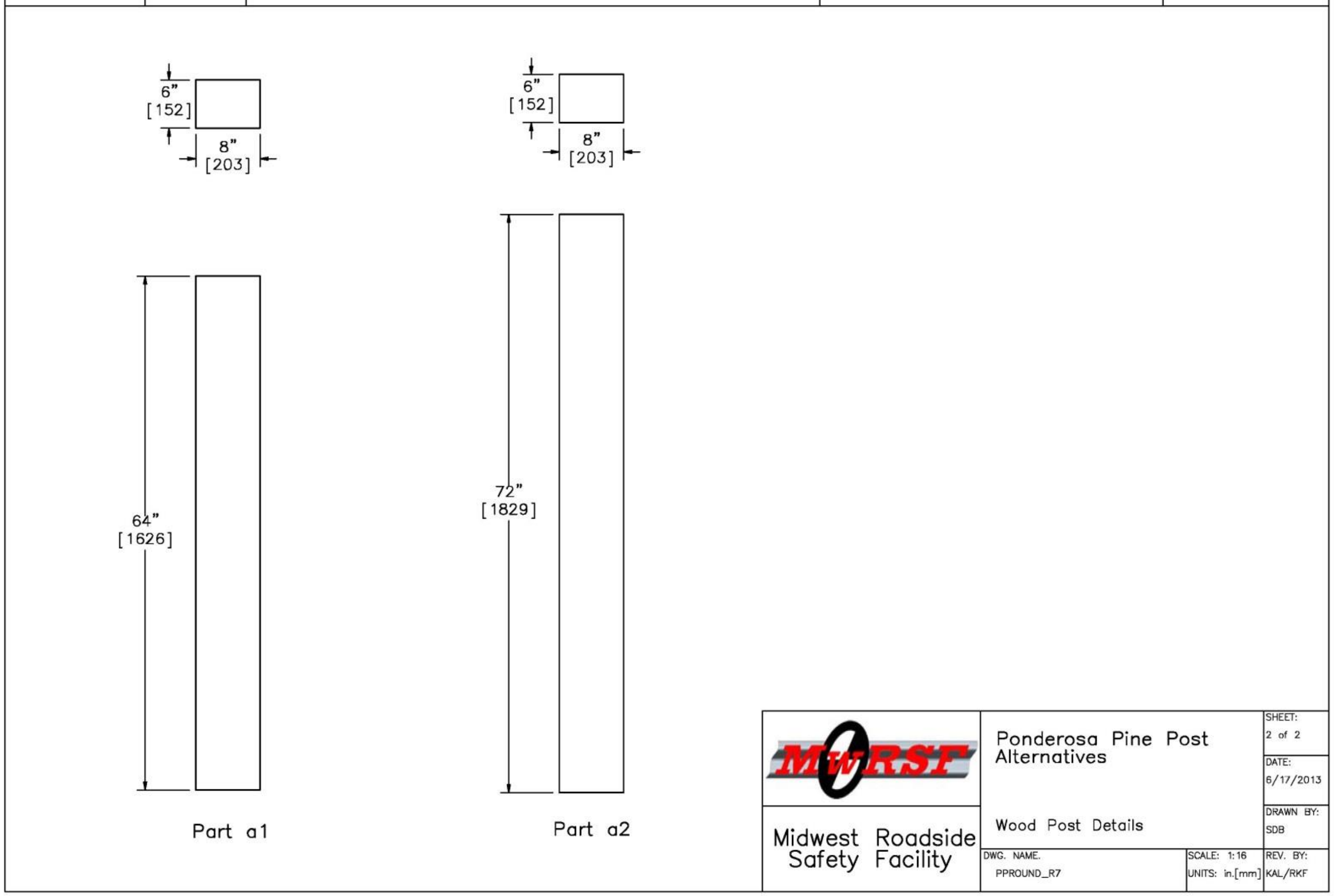


Figure 3. SYP Wood Posts – Round 1

5.3 Test Results

Results from each test are discussed in the following sections. Test results for all accelerometers are provided in Appendix C. The values described herein were calculated from the DTS-SLICE unit.

5.3.1 Test No. AZSYP-1

During test no. AZSYP-1, the bogie impacted the 6-in. x 8-in. x 71¾-in. (152-mm x 203-mm x 1,822-mm) long SYP wood post with a 43¼-in. (1,099-mm) embedment depth at a speed of 21.5 mph (34.6 km/h). Initially, the post began to rotate backward. However, by 0.01 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.055 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 11 in. (279 mm) below the ground line with only fibers holding the two pieces together.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 4. The post reached a peak force of 18.5 kips (82.3 kN) at 3.5 in. (89 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The post continued to provide resistance as the impact event progressed. However the force dropped to an average of 5.0 kips (2.2 kN) between 5 and 15 in. (127 and 381 mm) of deflection. The energy absorbed by the post was 104.1 kip-in. (15.8 kJ) by the conclusion of post fracture at 18.6 in. (472 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 5.

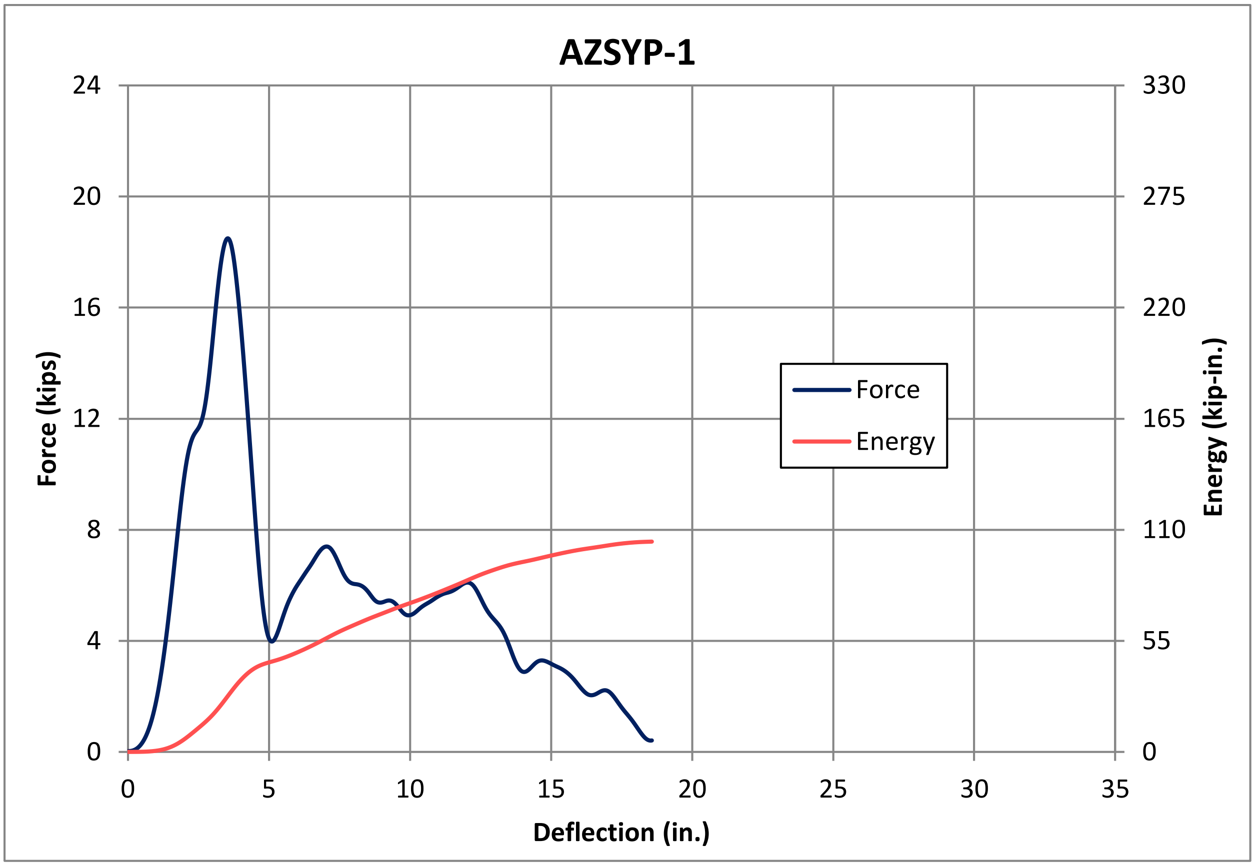


Figure 4. Force vs. Deflection and Energy vs. Deflection, Test No. AZSYP-1

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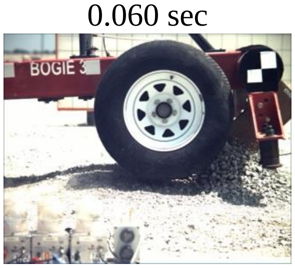

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Figure 5. Time-Sequential and Post-Impact Photographs, Test No. AZSYP-1

5.3.2 Test No. AZSYP-2

During test no. AZSYP-2, the bogie impacted the 6-in. x 8-in. x 71¾-in. (152-mm x 203-mm x 1,822-mm) long SYP wood post with a 43¼-in. (1,099-mm) embedment depth at a speed of 20.0 mph (32.2 km/h). Initially, the post began to rotate backward. However, by 0.015 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.055 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 13 in. (330 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 6. The post reached a peak force of 13.5 kips (60.1 kN) at 5.3 in. (135 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 92.4 kip-in. (10.4 kJ) by the completion of fracture at 17.6 in. (447 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 7.

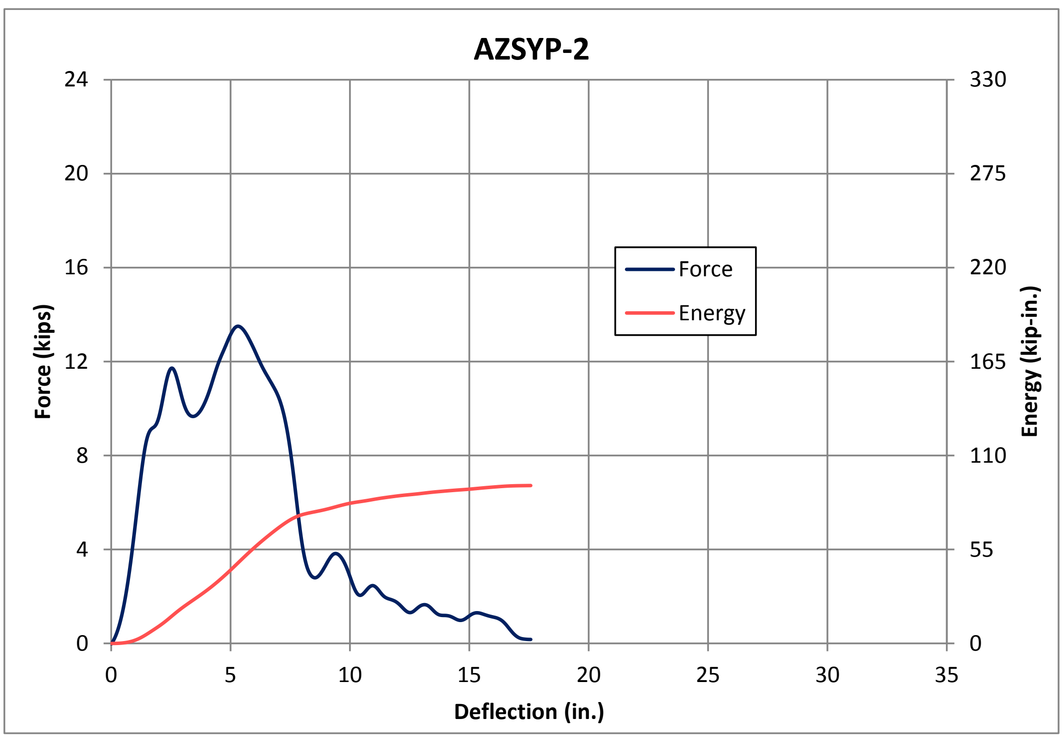

Figure 6. Force vs. Deflection and Energy vs. Deflection, Test No. AZSYP-2


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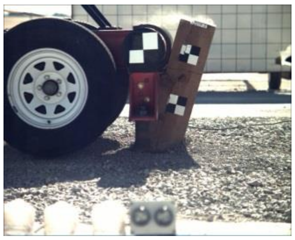
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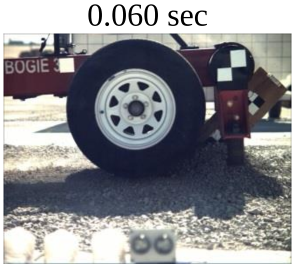
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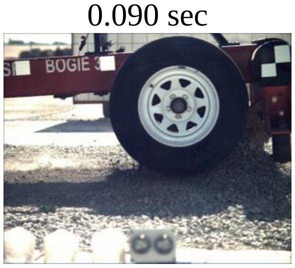
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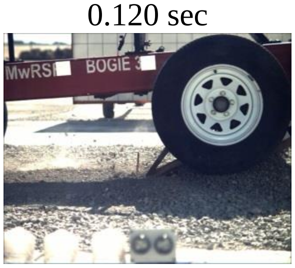
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Figure 7. Time-Sequential and Post-Impact Photographs, Test No. AZSYP-2

5.3.3 Test No. AZSYP-3

During test no. AZSYP-3, the bogie impacted the 6-in. x 8-in. x 71¾-in. (152-mm x 203-mm x 1,822-mm) long SYP wood post with a 43¼-in. (1,099-mm) embedment at a speed of 21.6 mph (34.8 km/h). The post rotated through the soil and pulled completely out of the ground during impact. The bogie overrode the post at a displacement of 63.7 in. (1,618 mm) as determined from the DTS-SLICE data. The wood post showed no signs of fracture when examined after the impact event.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 8. Early on, the forces quickly increased to a peak force of 16.4 kips (73.0 kN) at 4.9 in. (124 mm) of deflection. After this peak load was attained, the resistive force steadily decreased through approximately 40 in. (1,016 mm), after which the resistive force was around 1.0 kip (4.4 kN) for the rest of the impact event. The energy absorbed by the post was 224.0 kip-in. (25.3 kJ) through 20 in. (508 mm) of deflection, and 289.1 kip-in. (32.7 kJ) through 63.7 in. (1,618 mm). Time-sequential and post-impact photographs are shown in Figure 9.

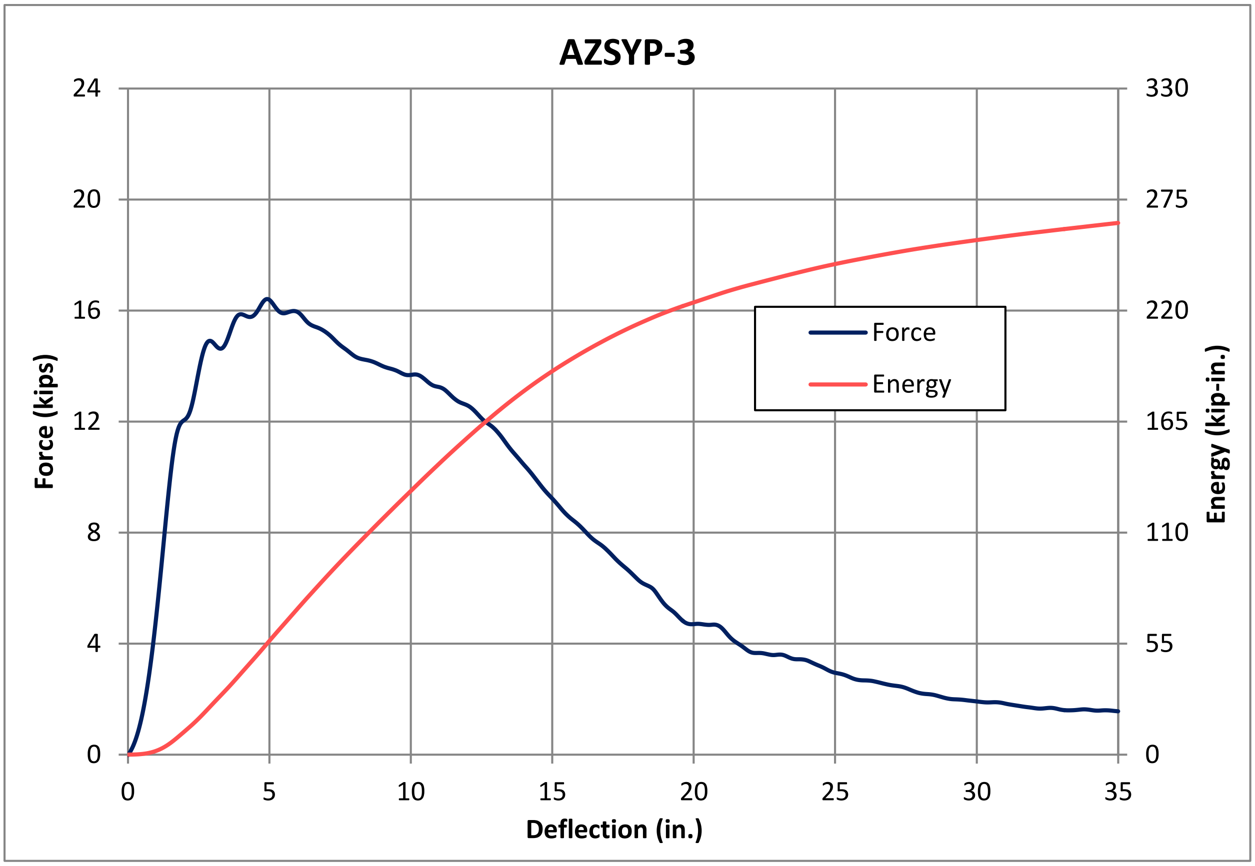
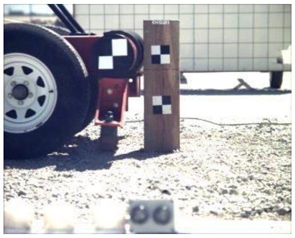


Figure 8. Force vs. Deflection and Energy vs. Deflection, Test No. AZSYP-3



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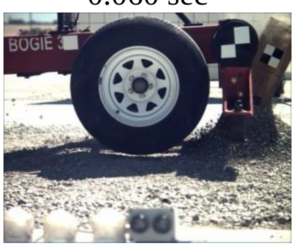

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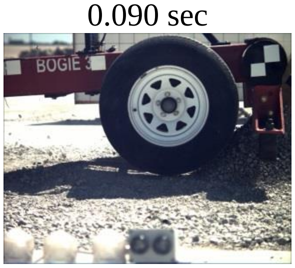

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Figure 9. Time-Sequential and Post-Impact Photographs, Test No. AZSYP-3

5.3.4 Test No. AZSYP-4

During test no. AZSYP-4, the bogie impacted the 6-in. x 8-in. x 64-in. (152-mm x 203-mm x 1,626-mm) long SYP wood post with a 35-in. (889-mm) embedment depth at a speed of 19.5 mph (31.4 km/h). Initially, the post began to rotate backward. However, by 0.007 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.038 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 1 in. (25 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 10. The post reached a peak force of 7.2 kips (32.2 kN) at 1.6 in. (41 mm) of deflection. At 2.4 in. (61 mm) of deflection, the post began to fracture, and the resistive force quickly declined. The energy absorbed by the post was 15.0 kip-in. (1.7 kJ) by the completion of fracture at 4.0 in. (102 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 11.

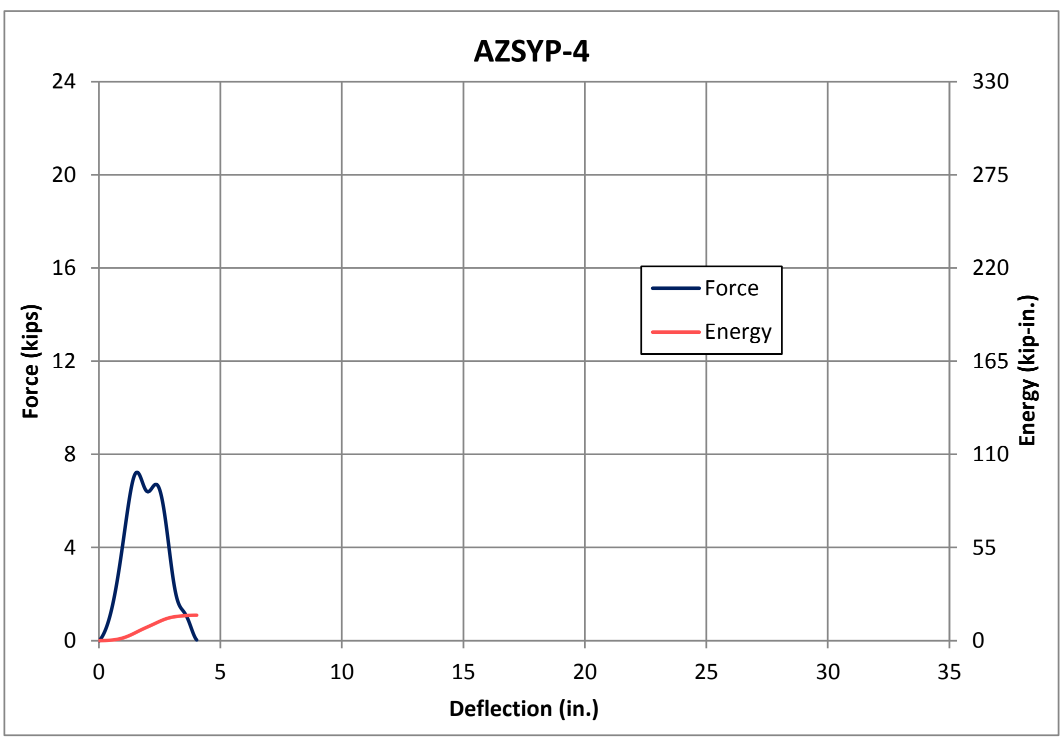

Figure 10. Force vs. Deflection and Energy vs. Deflection, Test No. AZSYP-4

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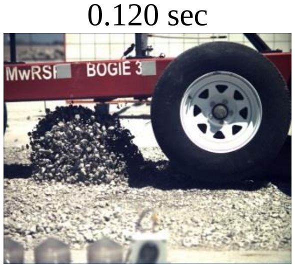

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Figure 11. Time-Sequential and Post-Impact Photographs, Test No. AZSYP-4

5.3.5 Test No. AZSYP-5

During test no. AZSYP-5, the bogie impacted the 6-in. x 8-in. x 64-in. (152-mm x 203-mm x 1,626-mm) long SYP wood post with a 35-in. (889-mm) embedment depth at a speed of 19.8 mph (31.9 km/h). The post rotated through the soil. The bogie overrode the post at a displacement of 31.3 in. (795 mm), as determined from the DTS-SLICE data. The post sustained cracking around a knot located 18 in. (457 mm) above the bottom of the post or 17 in. (432 mm) below the ground.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 12. Early on, the resistive force quickly increased to a peak of 11.1 kips (49.4 kN) at 4.4 in. (112 mm) of deflection. After this peak load was attained, the resistive force steadily decreased for the remainder of the impact event. The energy absorbed by the post was 140.4 kip-in. (15.9 kJ) through 20 in. (508 mm) of deflection and 153.5 kip-in. (17.3 kJ) through 31.3 in. (795 mm). Time-sequential and post-impact photographs are shown in Figure 13.

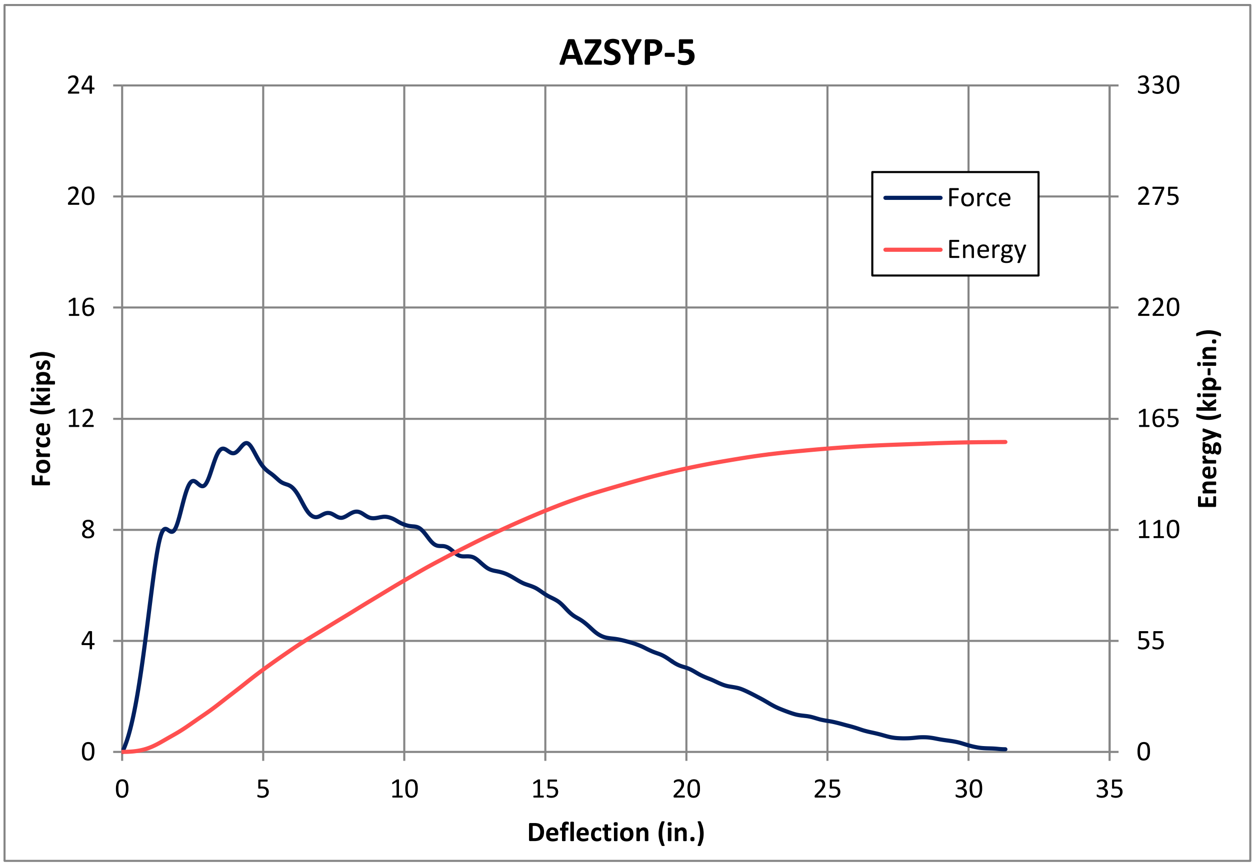
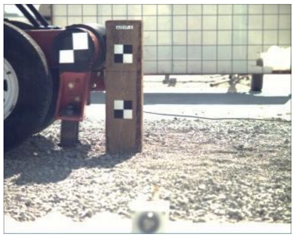


Figure 12. Force vs. Deflection and Energy vs. Deflection, Test No. AZSYP-5



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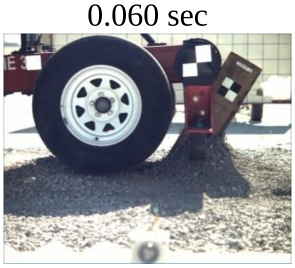

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Figure 13. Time-Sequential and Post-Impact Photographs, Test No. AZSYP-5

5.3.6 Test No. AZSYP-6

During test no. AZSYP-6, the bogie impacted the 6-in. x 8-in. x 64-in. (152-mm x 203-mm x 1,626-mm) long SYP wood post with a 35-in. (889-mm) embedment depth at a speed of 21.4 mph (34.4 km/h). The post rotated through the soil, and the bogie overrode the top of the post at a displacement of 32.2 in. (818 mm), as determined from the DTS-SLICE data. The wood post showed no signs of fracture when examined after the impact event.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 14. Early on, the resistive force quickly increased to a peak of 13.0 kips (57.8 kN) at 5.0 in. (127 mm) of deflection. After this peak load was attained, the resistive force steadily decreased for the remainder of the impact event. The energy absorbed by the post was 169.8 kip-in. (19.2 kJ) through 20 in. (508 mm) of deflection, and 187.7 kip-in. (21.2 kJ) through 32.2 in. (818 mm). Time-sequential and post-impact photographs are shown in Figure 15.

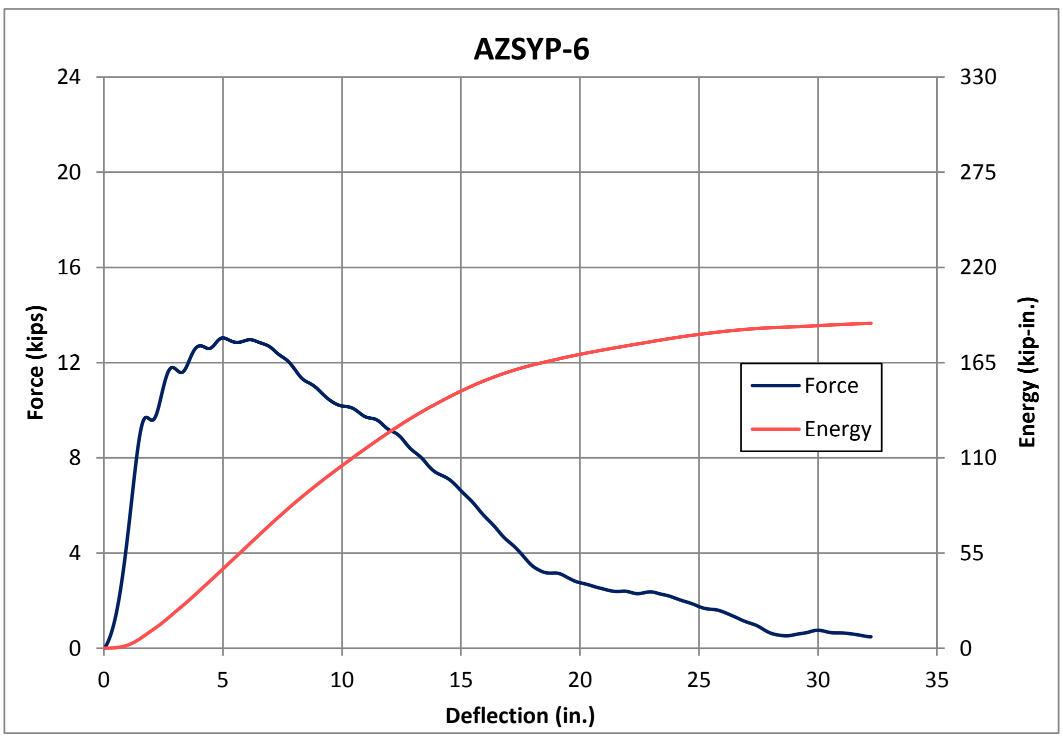
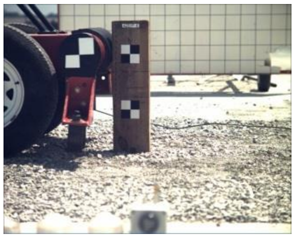


Figure 14. Force vs. Deflection and Energy vs. Deflection, Test No. AZSYP-6



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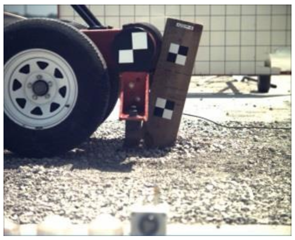

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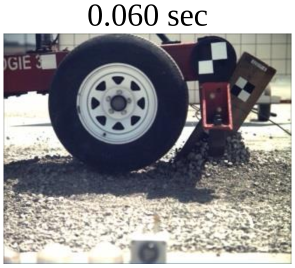

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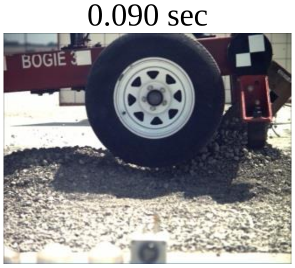

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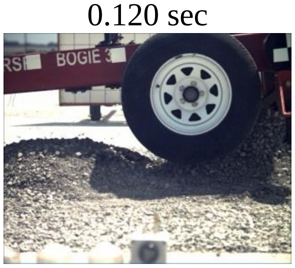

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Figure 15. Time-Sequential and Post-Impact Photographs, Test No. AZSYP-6

5.4 Discussion

Six tests were conducted on 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts at two different lengths in order to establish the force versus deflection and energy versus displacement characteristics for each post length. The results from the six bogie tests are summarized in Table 4. The force vs. deflection comparison curves are shown in Figures 16 and 17 for the 72-in. (1,829-mm) and 64-in. (1,626-mm) long posts, respectively. Two of the 72-in. (1,829-mm) long SYP posts fractured, while only one of the 64-in. (1,626-mm) long SYP posts fractured. The energy vs. deflection curves are shown in Figures 18 and 19 for the 72-in. (1,829-mm) and 64-in. (1,626-mm) long posts, respectively.

Table 4. Bogie Test Results of 6-in. x 8-in. (152 mm x 203 mm) SYP Wood Posts

Test No.	Post Length in. (mm)	Post Embedment in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Deflection at Peak Force in. (mm)	Average Force kips (kN)			Absorbed Energy kip-in. (kJ)			Maximum Deflection in. (mm)	Post-Soil Behavior
						@ 10"	@ 15"	@ 20"	@ 10"	@ 15"	@ 20"		
AZSYP-1	71¾ (1,822)	43¼ (1,099)	21.5 (34.6)	18.5 (82.3)	3.5 (89)	7.3* (32.5)	6.4* (28.5)	NA	73.8* (8.3)	97.2* (11.0)	NA	18.6 (472)	Post Fracture
AZSYP-2	71¾ (1,822)	43¼ (1,099)	20.0 (32.2)	13.5 (60.0)	5.3 (135)	8.1* (36.0)	5.8* (25.8)	NA	82.1* (9.3)	90.3* (10.2)	NA	17.6 (447)	Post Fracture
AZSYP-3	71¾ (1,822)	43¼ (1,099)	21.6 (34.8)	16.4 (73.0)	4.9 (124)	13.2 (58.7)	12.7 (56.5)	10.8 (48.0)	130.8 (14.8)	190.0 (21.5)	224.0 (25.3)	63.7 (1,618)	Rotation in Soil
AVERAGE FOR 72" (1,828 mm) LONG POSTS				**16.1 (71.8)**	**4.6 (116)**	**13.2 (58.7)**	**12.7 (56.5)**	**10.8 (48.0)**	**130.8 (14.8)**	**190.0 (21.5)**	**224.0 (25.3)**		
AZSYP-4	64 (1,626)	35 (889)	19.5 (31.4)	7.2 (32.2)	1.6 (40.6)	NA	NA	NA	NA	NA	NA	4.0 (102)	Post Fracture
AZSYP-5	64 (1,626)	35 (889)	19.8 (31.9)	11.1 (49.4)	4.4 (112)	8.5 (37.8)	7.9 (35.1)	6.9 (30.7)	84.9 (9.6)	119.5 (13.5)	140.4 (15.9)	31.3 (795)	Rotation in Soil
AZSYP-6	64 (1,626)	35 (889)	21.4 (34.4)	13.0 (57.8)	5.0 (127)	10.6 (47.2)	9.9 (44.0)	8.2 (36.5)	105.6 (11.9)	148.7 (16.8)	169.8 (19.2)	32.2 (818)	Rotation in Soil
AVERAGE FOR 64" (1,626 mm) LONG POSTS				**10.4 (46.5)**	**3.7 (93)**	**9.6 (42.5)**	**8.9 (39.6)**	**7.6 (67.2)**	**95.3 (10.8)**	**134.1 (15.2)**	**155.1 (17.6)**		

*Post fracture had begun prior to reaching the listed deflection. Thus, value not used in computing average resistance and energies.

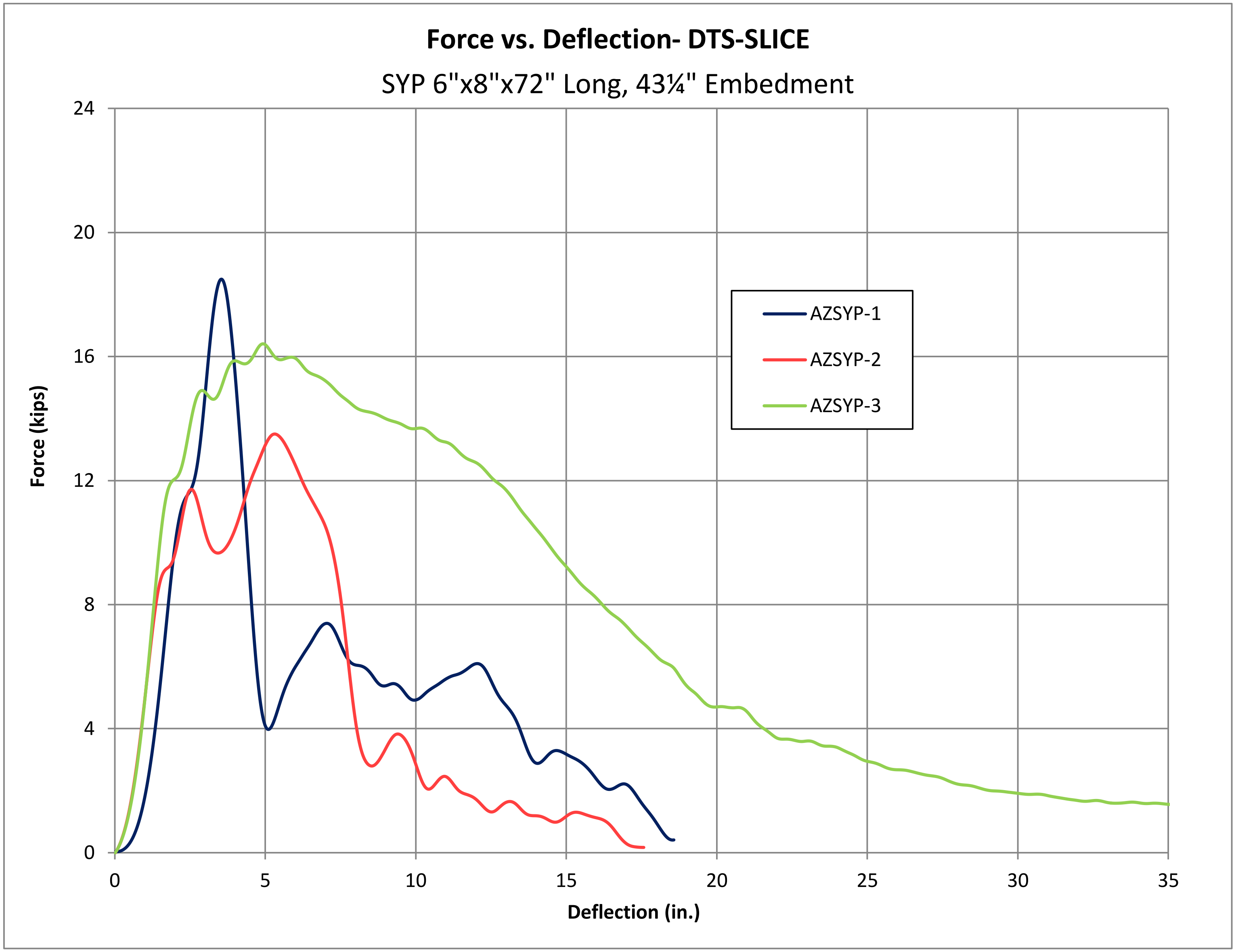


Figure 16. Force vs. Deflection, Test Nos. AZSYP-1 through AZSYP-3

Figure 17. Force vs. Deflection, Test Nos. AZSYP-4 through AZSYP-6

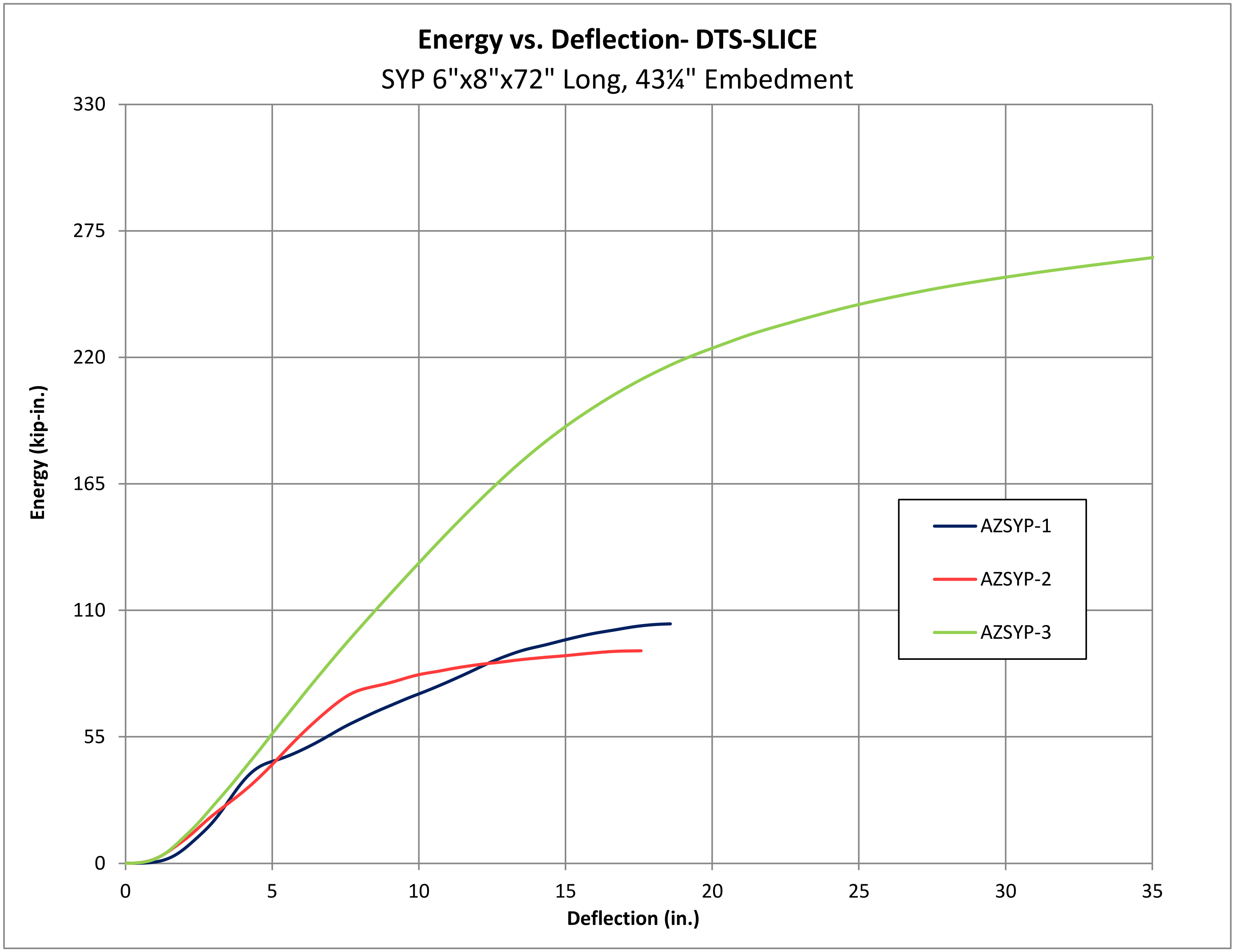


Figure 18. Energy vs. Deflection, Test Nos. AZSYP-1 through AZSYP-3

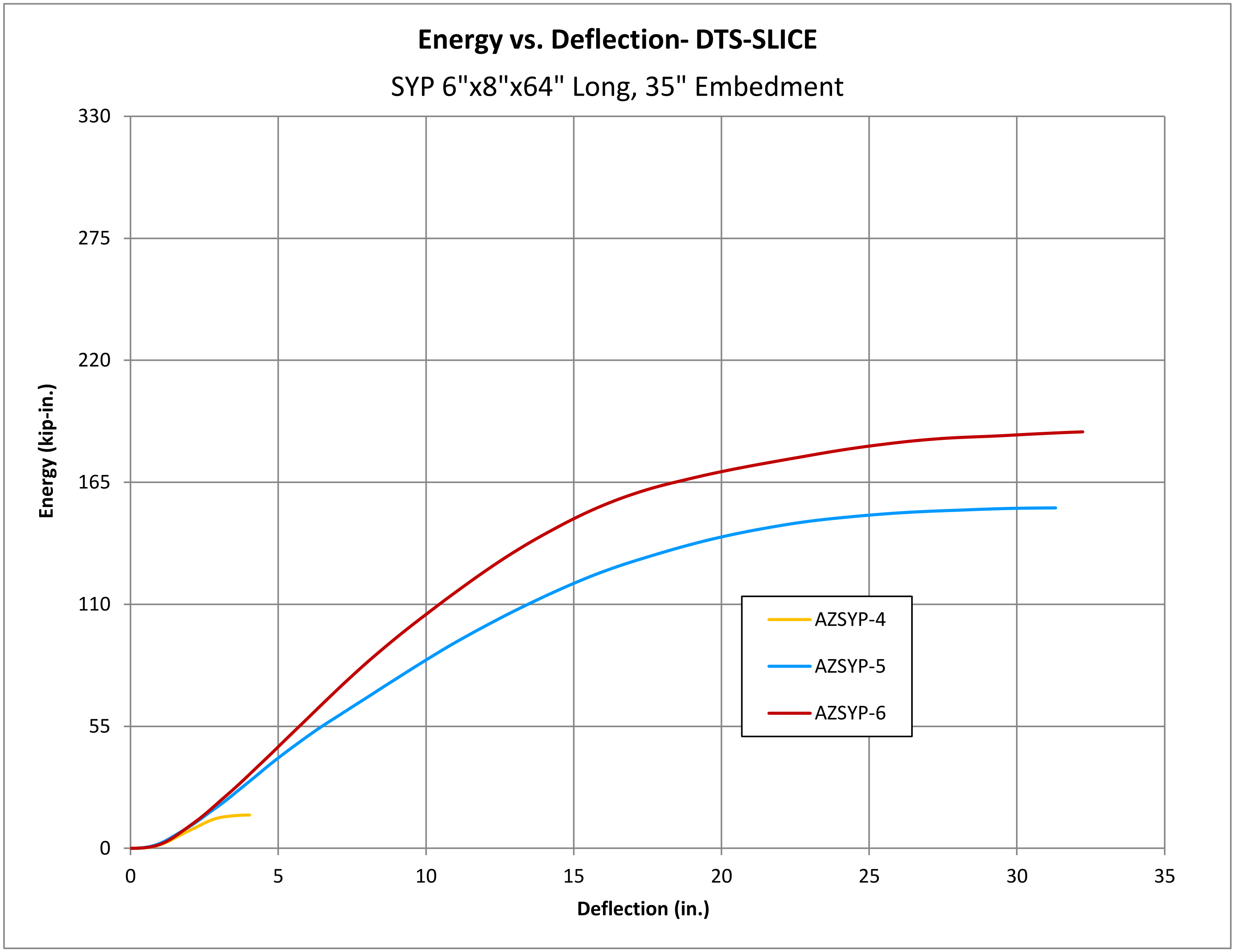


Figure 19. Energy vs. Deflection, Test Nos. AZSYP-4 through AZSYP-6

6 PRELIMINARY PP POST SIZE

Following the completion of the bogie tests on rectangular SYP posts, it was necessary to estimate the initial diameter and embedment depth for round PP posts. Upon selection, the newly-configured PP posts would need to be successfully tested and evaluated in order to be considered as a surrogate post for use in the standard AzDOT G4(2W) guardrail system. The AzDOT W-beam guardrail system utilizes 6-in. x 8-in. (152-mm x 203-mm) by 64-in. (1,626-mm) long SYP posts, a 28-in. (711-mm) top rail height, and a 35-in. (889-mm) embedment depth. The diameter and length of PP posts should provide similar post-soil behavior to that found for rectangular SYP posts. In addition, the PP posts should allow for rotation in common roadside soils, provide adequate structural capacity, and generate energy dissipation characteristics similar to the accepted SYP rectangular posts.

Test nos. AZSYP-4 through AZSYP-6 were performed on AzDOT standard SYP posts. However, test no. AZSYP-4 provided little insight on post-soil behavior due to fracture of the wood post. Thus, the average and peak forces for AzDOT standard post were calculated by averaging only the results from test nos. AZSYP-5 and AZSYP-6, as shown previously in Table 4.

The required post diameters to prevent fracture under a given load can be calculated using Equation 1, originally presented in Hascall, et al. [5].

$$\mathrm{D} = \sqrt[3]{\frac{32(M)}{\pi(MOR)}} \tag{1}$$

where D = Post Diameter
M = Applied Moment
MOR = Modulus of Rupture

The MOR values for the PP material were acquired from previous dynamic impact tests of round PP posts [5]. Due to the variability of timber properties, calculations were conducted using both average and minimum MOR values from that test series. The minimum PP post diameter was calculated using peak force and moment obtained from the tests conducted on the 6-in. x 8-in. (152-mm x 203-mm) SYP posts previously provided in Chapter 5. The PP post diameter was also determined using an estimated peak value based on the average load increased by 33 percent. Using an average of all four calculated diameters, the minimum PP post diameter for the AzDOT standard was found to be approximately 8 in. (203 mm). Subsequently, the calculated diameter was increased by approximately ¼ in. (6 mm) to provide a factor of safety, thus resulting in an initial post diameter of 8¼ in. (210 mm) for the Round 2 testing program and to serve as a surrogate in the AzDOT G4(2W) guardrail system. These calculations are shown in Table 5.

The required embedment depths were calculated using Equation 2, which was derived from Equation A3-2 found in MASH [17] after making adjustments for different load heights. This equation relates force, impact height, and embedment depths for various post-in-soil configurations.

$$\mathrm{ED} = \sqrt{\frac{F(H)}{F_1(H_1)\left(\frac{1}{ED_1}\right)^2}} \qquad (2)$$

where ED = Embedment Depth (alternative 2)
F = Average Force (alternative 2)
H = Load Height (alternative 2)
F_1 = Average Force (alternative 1 – baseline or reference test)
H_1 = Load Height (alternative 1 – baseline or reference test)
ED_1 = Embedment Depth (alternative 1 – baseline or reference test)

Similar to determining post diameter, peak and average forces from test nos. AZSYP-5 and AZSYP-6 were used to calculate embedment depth for round PP posts. In addition, dynamic test results from two different studies on round timber posts embedded in strong soil were used as baseline or reference tests. As shown in Table 5, four embedment depths were calculated for the AzDOT guardrail standard using average and peak forces and then averaged to determine one initial embedment depth The initial embedment depth for a PP post, used with the AzDOT guardrail standard, was found to be 37.87 in. (962 mm). Subsequently, the embedment depth for a PP post was conservatively rounded down to the nearest inch, 37 in. (940 mm). Therefore, an 8¼-in. (210-mm) diameter by 66-in. (1,676-mm) long PP post with an embedment depth of 37 in. (940 mm) was planned for testing and evaluation in order potentially serve as a surrogate for rectangular SYP posts in the AzDOT standard for rectangular posts.

For informational purposes, the revised calculated diameter, length, and embedment depth to meet the U.S. standard W-beam guardrail consisted of a 9¼-in. (235-mm) diameter by approximately 72-in. (1,829-mm) long PP post with an embedment depth of 43¼ in. (1,099 mm).

Table 5. Initial PP Post Diameter and Embedment Depth

Post Dimension Determination from Past Data	AzDOT std.	US std.
Top of Rail Height (in.)	28	27.75
Center Rail Height or Impact Height, H, (in.)	21.875	21.65
Post Length (in.)	64	72
Top of Post (in.)	29	28.75
Embedment Depth (in.)	35	43.25
Results from Test nos. AZSYP-1 through 6		
Avg. Force @ 15" (kips)	8.9	12.7
Peak Force (kips)	12.1	16.1
Adjusted Moment {F_{ave}*H*1.33} (k-in.)	258.9	365.7
Peak Moment {F_{peak}*H} (k-in.)	264.7	348.6
DIAMETER CALCULATION		
$D = \sqrt[3]{\frac{32(M)}{\pi(MOR)}}$		
PP MOR_{ave} = 5.66 ksi [Hascal - Round 1 BASELINE]		
Diameter from M_{ave} (in.)	7.75	8.70
Diameter from M_{peak} (in.)	7.81	8.56
PP MOR_{min} = 4.99 ksi [Hascal - Round 1 BASELINE]		
Diameter from M_{ave} (in.)	8.09	9.07
Diameter from M_{peak} (in.)	8.14	8.93
Average of Calculated Diameters (in.)	7.95	8.81
EMBEDMENT DEPTH CALCULATION		
$ED = \sqrt{\frac{F(H)}{(F_1)(H_1)\left(\frac{1}{ED_1}\right)^2}}$		
F_1 = 8.49 kips, H_1 = 24.875", ED_1 = 37" (Hascal - PP-34) [5]		
Embedment Depth from F_{ave} (in.)	35.53	42.22
Embedment Depth from F_{peak} (in.)	41.42	47.53
F_1 = 11.3 kips, H_1 = 21", ED_1 = 38" [Jeyapalan - C3] [7]		
Embedment Depth from F_{ave} (in.)	34.42	40.90
Embedment Depth from F_{peak} (in.)	40.13	46.05
Average of Calculated Embedment Depths (in.)	37.87	44.18
Suggested Dimensions for Round 2 Bogie Testing		
PP Minimum Diameter (in.)	8 1/4	9 1/4
PP Embedment Depth (in.)	37	43 1/4

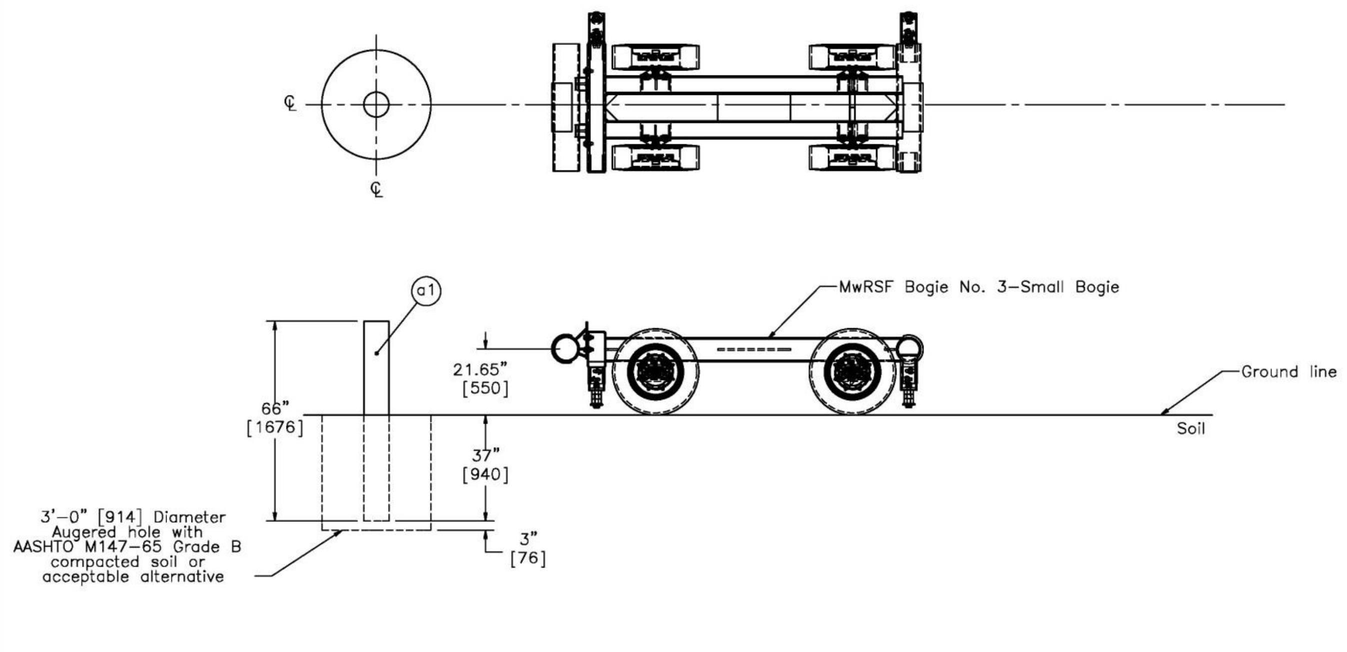
7 DYNAMIC TESTING – ROUND 2 – PP POSTS

7.1 Scope

Three bogie tests were conducted on 8¼-in. (210-mm) diameter round PP posts embedded in soil. In test nos. AZPP-1 through AZPP-3, a 66-in. (1,676-mm) long post was embedded to a depth of 37 in. (940 mm). A compacted, coarse, crushed limestone material was utilized for all tests, as recommended by MASH [17]. The target impact speed was 20.0 mph (32.2 km/h). The angle of impact was irrelevant; since, a round cross-section does not have a strong or weak axis. Because the rail heights for the AzDOT and U.S. standards differed by less than ¼ in. (6 mm), the three posts were impacted at a height of 21.65 in. (550 mm) above the ground line. The bogie testing matrix and the test setup are shown in Figures 20 and 21. Material specifications, mill certifications, and certificates of conformity for the round PP post material (test nos. AZPP-1 through AZPP-3, are provided in Appendix B.

It should be noted that the round PP posts were soaked in order to ensure that a saturated moisture condition existed at the time of testing. The saturated moisture condition would result in decreased wood capacity and a conservative post size.

Test Quantity	Post Species	Groundline Diameter in. [mm]	Embedment Depth in. [mm]	Top of Post Height in. [mm]	Post Length in. [mm]	Load Height in. [mm]	Bogie No.	Bogie Speed mph [km/h]
3	PP	8 1/4 [210]	37 [940]	29 [737]	5'–6" [1676]	21.65 [550]	3	20 [32.2]



Notes: (1) For the load height of 21.65" [550], the rear bumper of the small bogie may be used as the impact head.

(2) It was desired that a load height of 21 7/8" [556] be used for the 8 1/4" [210] diameter PP posts. For ease of testing, a 21.65" [550] load height can be used.

(3) Need to determine whether round posts should be soaked before testing.

MwRSF	Ponderosa Pine Post Alternatives		SHEET: 1 of 2
			DATE: 7/24/2012
Midwest Roadside Safety Facility	Ponderosa Pine Test Setup		DRAWN BY: CWP
	DWG. NAME. PPROUND_round2_R2	SCALE: 1:44 UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 20. Bogie Testing Matrix and Setup – PP Posts (Round 2)

Item No.	QTY.	Description	Material Specification	Hardware
a1	3	8 1/4" [210] Dia., 66" [1676] Long Ponderosa Pine Post	* see below	–

*PP Round Post Grading Criteria

General:
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 8¼–in. (210) diameter guardrail posts will be a minimum of 66 in. (1676) long. The use of peeler cores is prohibited.

Size:
The size of the posts shall be classified based on their diameter at the ground–line and their length. The ground–line diameter shall be specified by diameter in ¼ in. (6) breaks. The length shall be specified in 12 in. (305) 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 3 in. (76) longer. The diameter of the PP posts shall be 8¼ in. (210) at the ground line with an upper limit of 9 in. (229).

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. (25).

Shape and Straightness:
All PP 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 1¼ in. (32) 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 exceeding 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.

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3.5 in. (89) or smaller.

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 treated post shall have a minimum sapwood depth of ¾ in. (19), 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.

Decay:
Allowed in knots only.

Holes:
Pin holes 1/16 in. (1) or less are not restricted.

Slope of Grain:
1 in 10.

Compression Wood:
Not allowed in the outer 1 in. (25) or if exceeding ¼ of the radius.

Ring Density:
Ring density shall be at least 6 rings–per–inch, as measured over a 3 in. (76) distance.

Midwest Roadside Safety Facility

Ponderosa Pine Post Alternatives

Bill of Materials

SHEET: 2 of 2
DATE: 7/24/2012
DRAWN BY: CWP
DWG. NAME. PPROUND_round2_R2
SCALE: NONE
UNITS: in.[mm]
REV. BY: KAL/RKF

Figure 21. Bill of Materials – PP Posts (Round 2)

7.2 Test Results

Results from each test are discussed in the following sections. Test results for all accelerometers are provided in Appendix C. The values described herein were calculated from the DTS-SLICE unit.

7.2.1 Test No. AZPP-1

During test no. AZPP-1, the bogie impacted the 8.48-in. (215-mm) diameter x 66-in. (1,676-mm) long PP wood post with a 37 in. (940 mm) embedment depth at a speed of 18.9 mph (30.4 km/h). Initially, the post began to rotate backward. However, by 0.013 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.056 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 10 in. (254 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 22. The post reached a peak force of 14.7 kips (65.4 kN) at 4.3 in. (109 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 77.1 kip-in. (8.7 kJ) by the completion of post fracture. Time-sequential and post-impact photographs are shown in Figure 23.

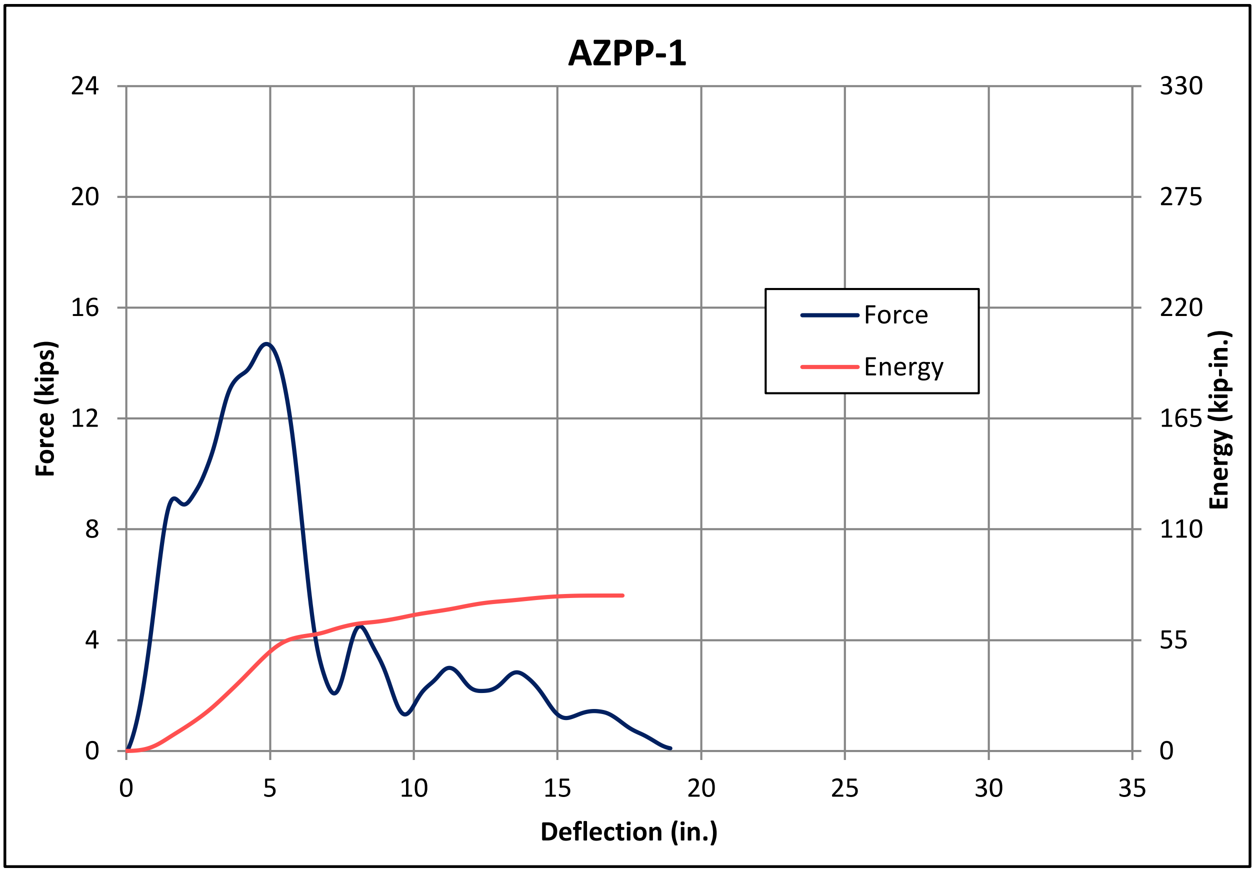
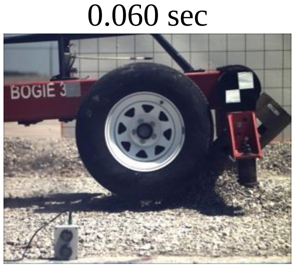


Figure 22. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-1

IMPACT

0.030 sec

0.060 sec



0.090 sec

0.120 sec

0.150 sec

Figure 23. Time-Sequential and Post-Impact Photographs, Test No. AZPP-1

7.2.2 Test No. AZPP-2

During test no. AZPP-2, the bogie impacted the 8.67-in. (220-mm) diameter x 66-in. (1,676-mm) long PP wood post with a 37 in. (940 mm) embedment depth at a speed of 21.3 mph (34.3 km/h). The post rotated through the soil. The bogie overrode the post at a displacement of 34.5 in. (876 mm), as determined from the DTS-SLICE data. The wood post showed no signs of fracture when examined after the impact event.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 24. Early on, the resistive force quickly increased to a peak of 14.3 kips (63.6 kN) at 5.0 in. (127 mm) of deflection. After this peak was attained, the resistive force steadily decreased for the remainder of the impact event. The energy absorbed by the post was 207.5 kip-in. (23.4 kJ) through 20 in. (508 mm) of deflection, and 243.5 kip-in. (27.5 kJ) through 34.5 in. (876 mm). Time-sequential and post-impact photographs are shown in Figure 25.

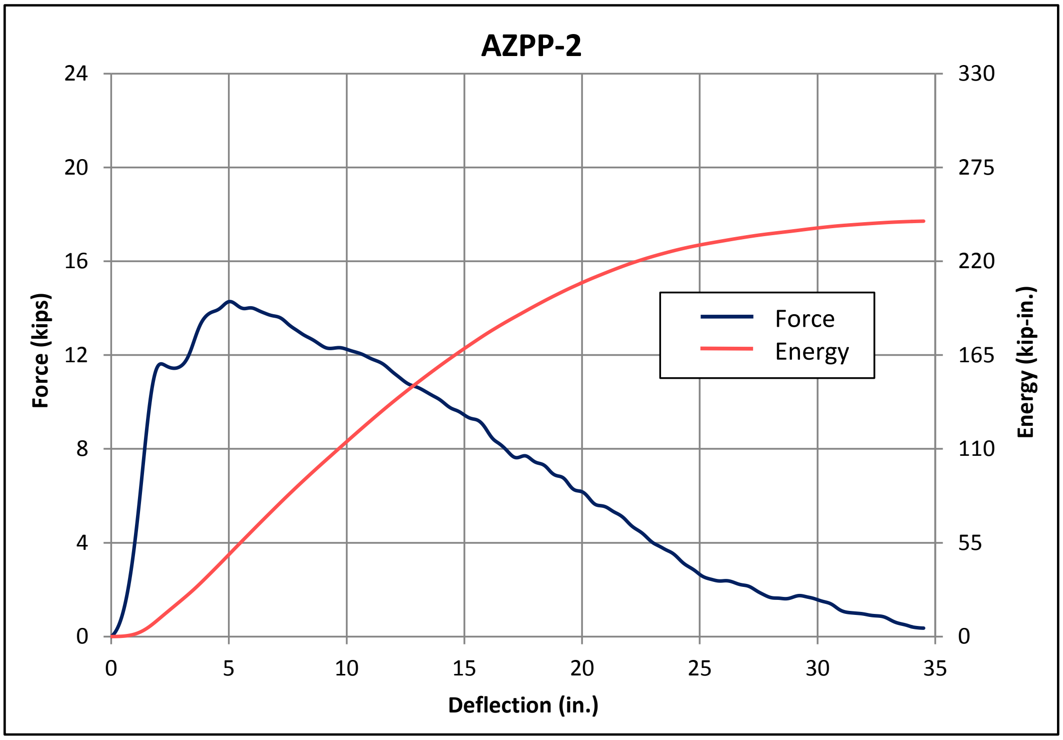
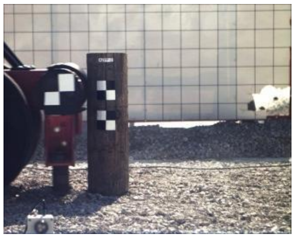


Figure 24. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-2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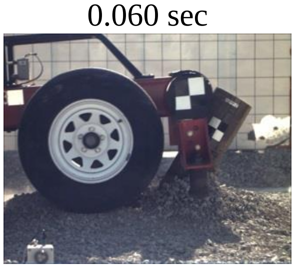
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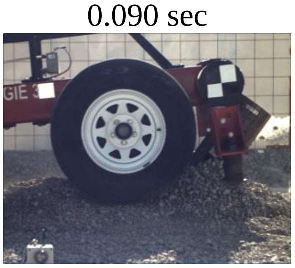
0.120 sec


0.150 sec

Figure 25. Time-Sequential and Post-Impact Photographs, Test No. AZPP-2

7.2.3 Test No. AZPP-3

During test no. AZPP-3, the bogie impacted the 8.48-in. (215-mm) diameter x 66-in. (1,676-mm) long PP wood post with a 37 in. (940 mm) embedment depth at a speed of 21.1 mph (34.0 km/h). Initially, the post began to rotate backward. However, by 0.011 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.018 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 8 in. (203 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 26. The post reached a peak force of 11.7 kips (52.0 kN) at 3.9 in. (99 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 41.4 kip-in. (4.7 kJ) by the completion of fracture. Time-sequential and post-impact photographs are shown in Figure 27.

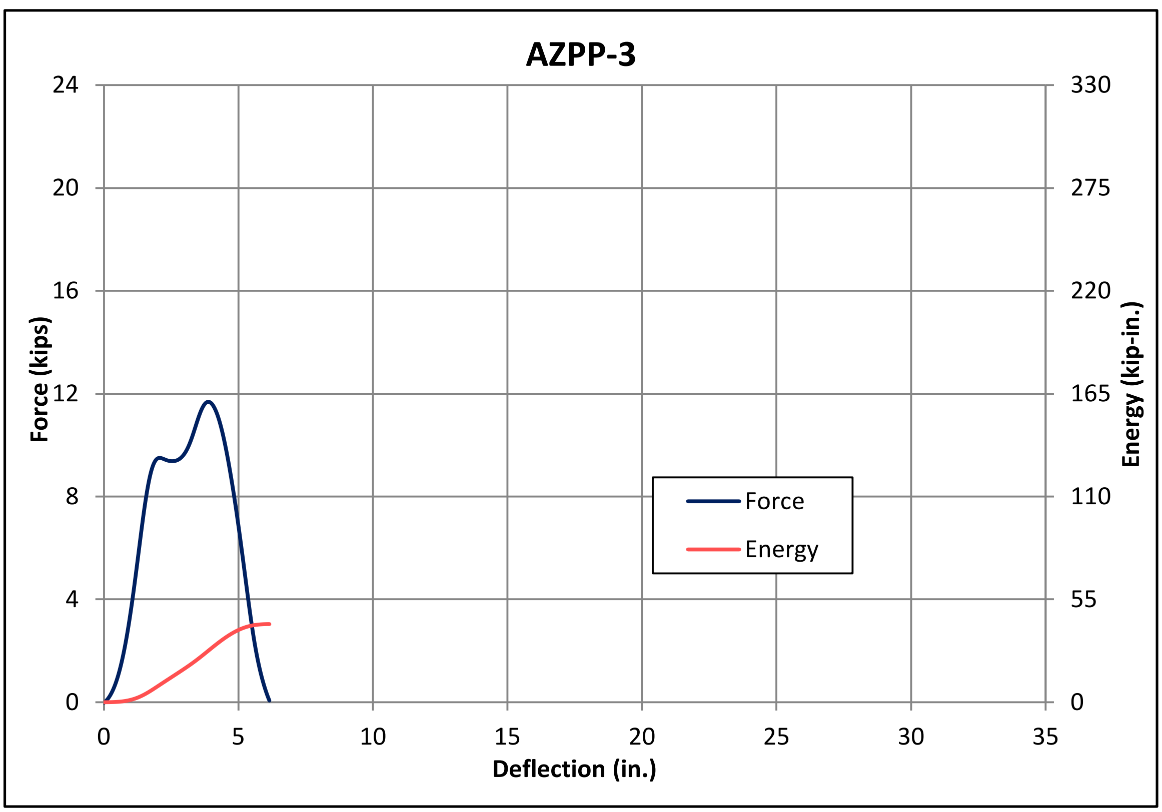

Figure 26. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-3

IMPACT

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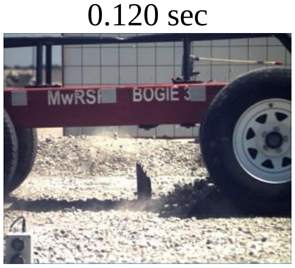


0.150 sec

Figure 27. Time-Sequential and Post-Impact Photographs, Test No. AZPP-3

7.3 Discussion

Three tests were conducted on PP posts with a targeted ground line diameter of 8¼ in. (210 mm) and a post length of 66 in. (1,676 mm) in order to establish the force versus deflection characteristics in soil. The results from the bogie testing matrix are summarized in Table 6. The posts used in test nos. AZPP-1 and AZPP-3 fractured, while the post used in test no. AZPP-2 rotated in the soil. A comparison of the force versus deflection curves are shown in Figure 28, while a comparison of the energy versus deflection curves are shown in Figure 29.

7.4 Comparison to SYP Posts

The results of the dynamic component tests conducted on PP wood posts (tests nos. AZPP-1 through AZPP-3) were compared to the qualifying results of the SYP wood posts (test nos. AZSYP-4 through AZSYP-6). When comparing post-soil resistance, only tests resulting in rotation in soil could be considered. Therefore, only test nos. AZSYP-5, AZSYP-6, and AZPP-2 were used. Comparison curves are shown in Figures 30 and 31.

The round PP post in test no. AZPP-2 provided a significant increase in resistance to rotation as compared to the rectangular SYP posts. Through 15 in. (381 mm) and 20 in. (508 mm) of deflection, the PP post absorbed 26 and 34 percent more than the average standard rectangular post. In addition, the peak forces for the PP tests (including those that broke) were, on average, higher than the rectangular SYP posts. Thus, the difference in cross-section and embedment depth led to an increase in post-soil resistance.

Table 6. Bogie Test Results of 8¼-in. (210-mm) Diameter x 66-in. (1,676-mm) long PP Posts, 37-in. (940-mm) Embedment

Test No.	Calculated Post Dia. at Groundline in. (mm)	Calculated Post Dia. 8" below Groundline in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Deflection at Peak Force in. (mm)	Average Force kips (kN)			Absorbed Energy kip-in. (kJ)			Maximum Deflection in. (mm)	Post-Soil Behavior
						@ 10"	@ 15"	@ 20"	@ 10"	@ 15"	@ 20"		
AZPP-1	8.48 (215)	8.39 (213)	18.9 (30.4)	14.7 (65.4)	4.3 (109)	6.6* (29.4)	5.0* (22.2)	NA	67.5* (7.6)	76.7* (8.7)	NA	17.3 (439)	Post Fracture
AZPP-2	8.67 (220)	8.62 (219)	21.3 (34.3)	14.3 (63.6)	5.0 (127)	11.5 (51.2)	11.3 (50.3)	10.2 (45.4)	114.5 (12.9)	169.0 (19.1)	207.5 (23.4)	34.5 (876)	Rotation in Soil
AZPP-3	8.48 (215)	8.46 (215)	21.1 (34.0)	11.7 (52.0)	3.9 (99)	NA	NA	NA	NA	NA	NA	6.2 (157)	Post Fracture
AVERAGE FROM AZSYP-4 THROUGH AZSYP-6				**10.4 (46.5)**	**3.7 (93)**	**9.6 (42.5)**	**8.9 (39.6)**	**7.6 (67.2)**	**95.3 (10.8)**	**134.1 (15.2)**	**155.1 (17.6)**		

*Post fracture had begun prior to reaching the deflection listed. Thus, value not used in computing average resistance and energies.

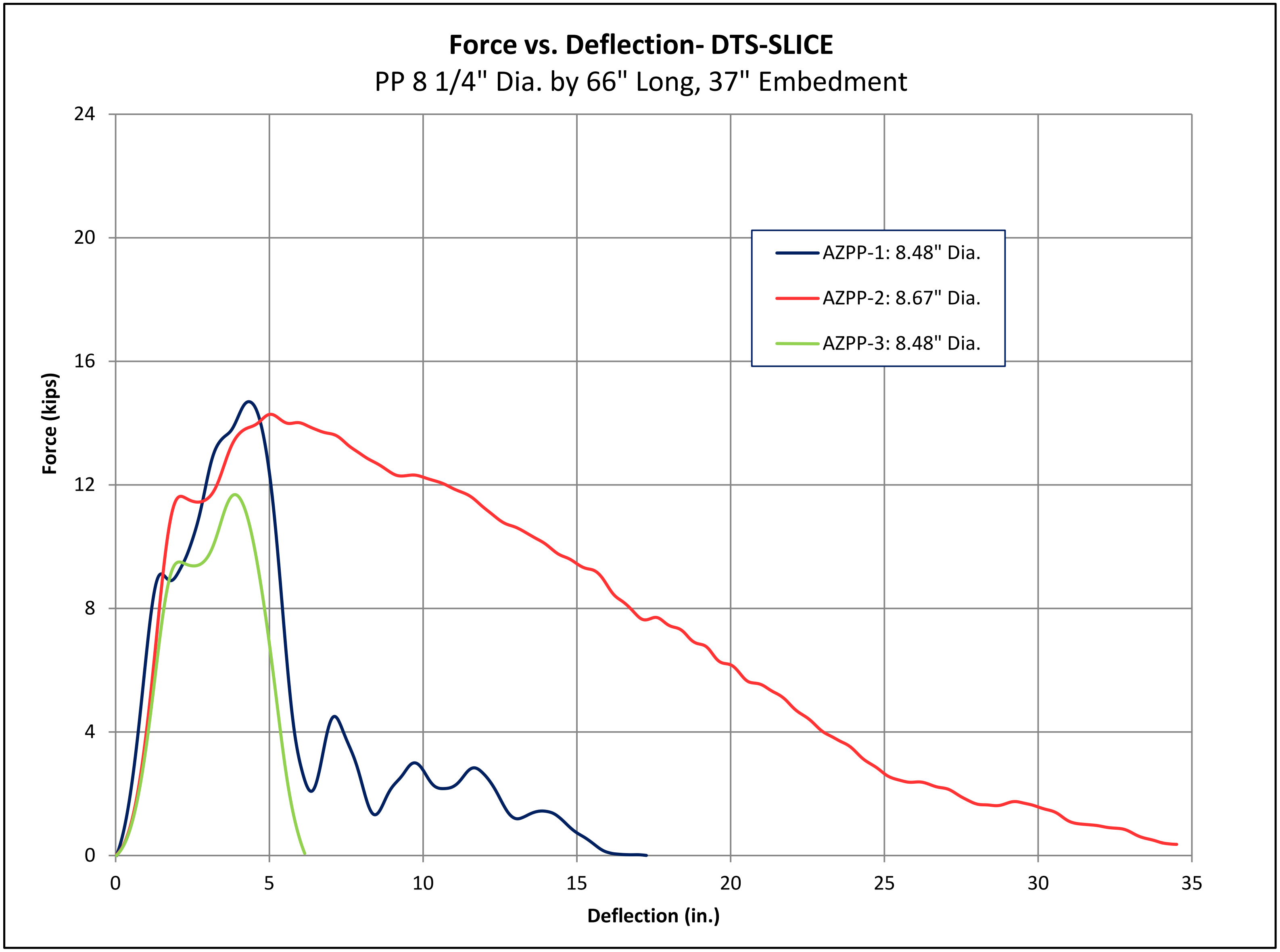


Figure 28. Force vs. Deflection Comparison, Test Nos. AZPP-1 through AZPP-3

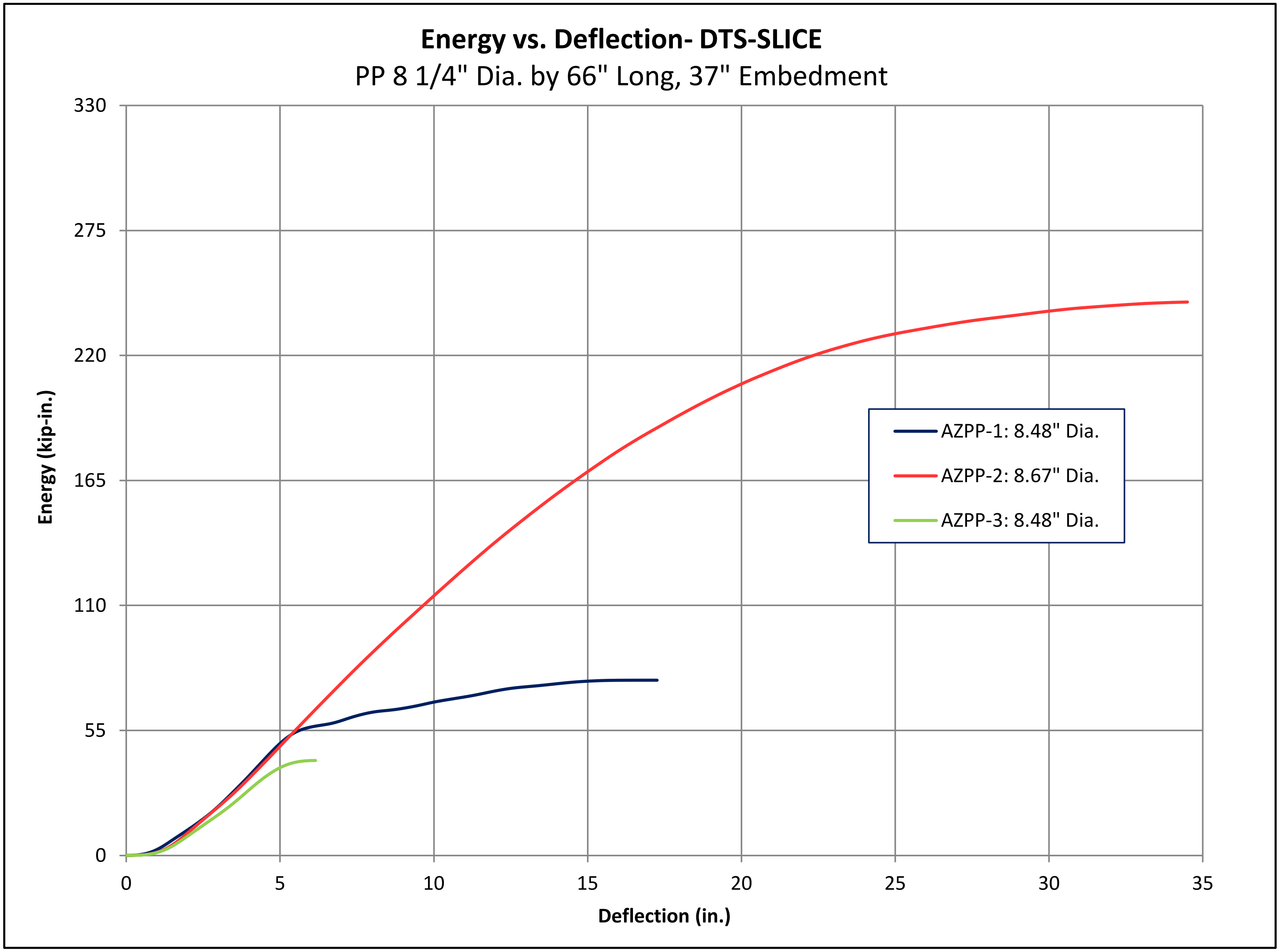


Figure 29. Energy vs. Deflection Comparison, Test Nos. AZPP-1 through AZPP-3

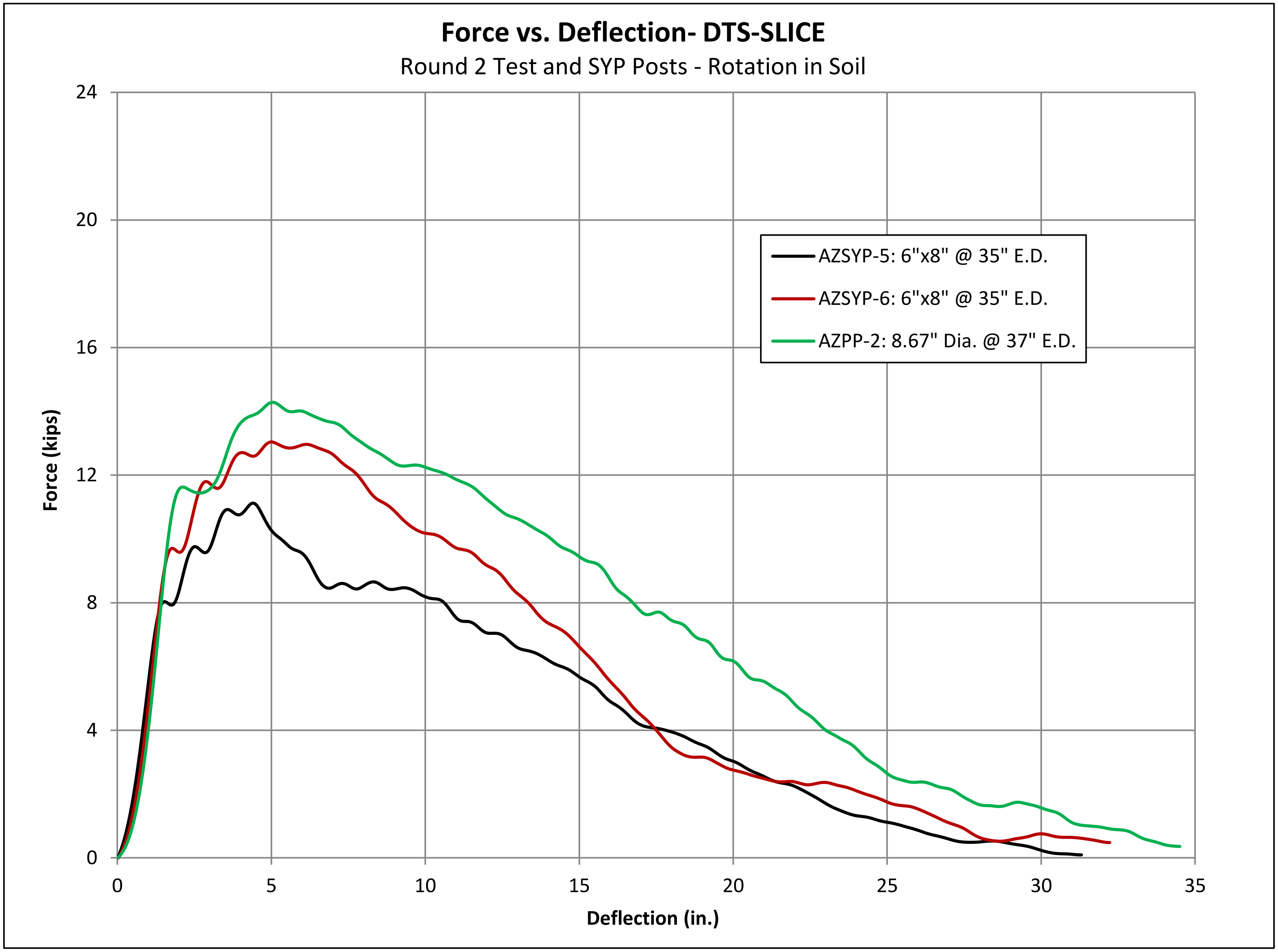


Figure 30. Force vs. Deflection Comparison, Test Nos. AZSYP-5, AZSYP-6, and AZPP-2

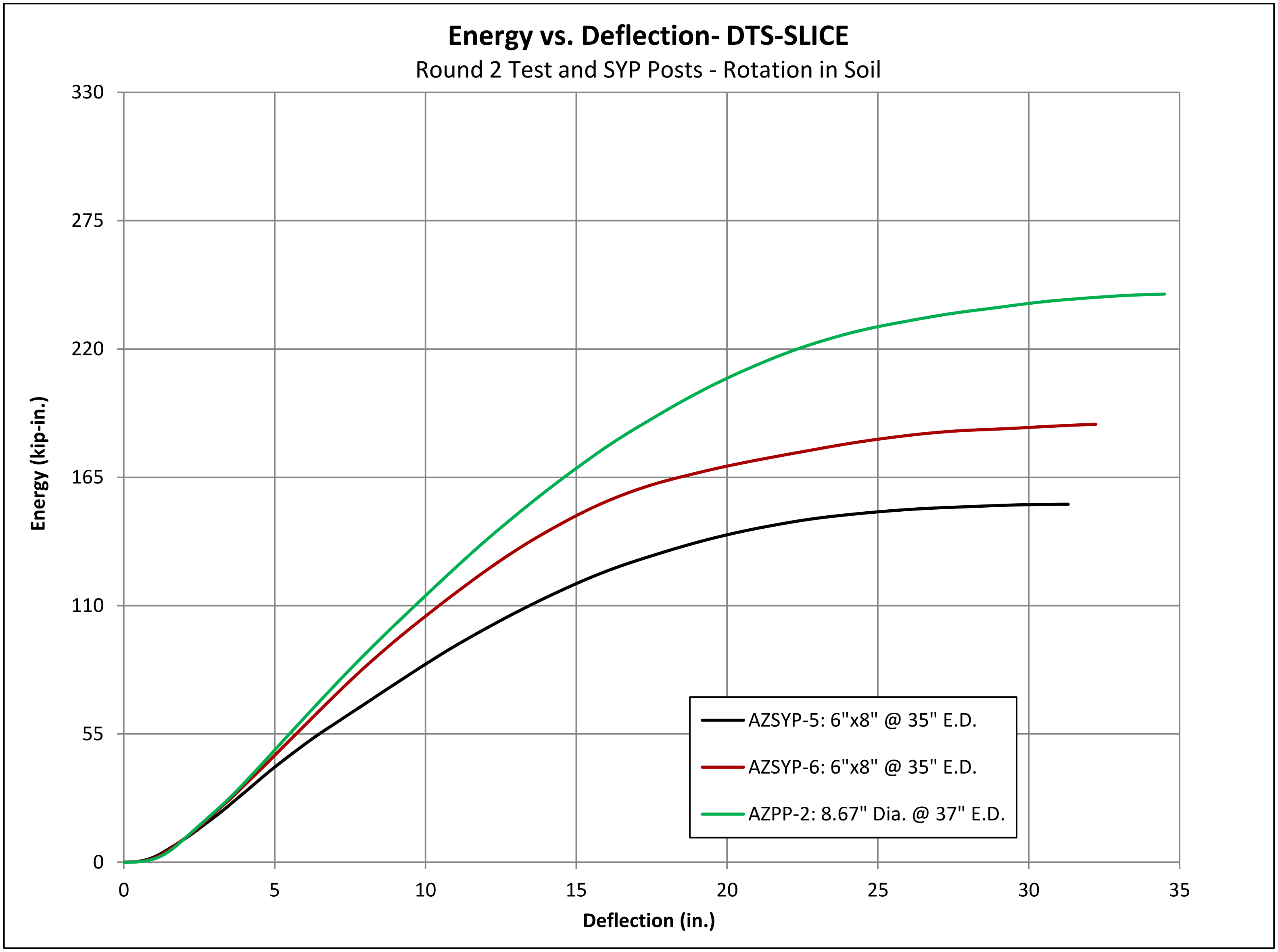


Figure 31. Energy vs. Deflection Comparison, Test Nos. AZSYP-5, AZSYP-6, and AZPP-2

8 PP POST SIZE ADJUSTMENT

After the Round 2 bogie testing program was completed on the PP posts, it was determined that additional testing would be necessary to identify an equivalent round PP post for meeting the AzDOT standard. Only one of the three PP posts did not fracture (test no. AZPP-2), and the force and energy curves were higher than those experienced by the rectangular SYP posts. Thus, the dimensions of the round PP posts would need to be adjusted. The diameter needed to be increased to strengthen the post and prevent fracture. In addition, a shallower embedment depth would help to reduce the post-soil resistive force.

Because test nos. AZPP-1 and AZPP-3 fractured, only data from test no. AZPP-2 was used to determine the adjusted diameter. The ground line diameter of AZPP-2 was calculated as 8.67 in. (220 mm) using the measured circumference, which was far larger than the targeted minimum value of 8¼ in. (210 mm). Therefore, it was determined that the required minimum diameter should be increased to 8½ in. (216 mm) to strengthen the post.

The next step was to adjust the embedment depth of the round PP post in order to obtain force and energy values similar to those experienced by the rectangular SYP posts in test nos. AZSYP-5 and AZSYP-6. The adjusted embedment depth was estimated using Equation 3, which was obtained from MASH [17]. The average peak force between the two SYP tests, 12.1 kips (53.8 kN), was set as P_2, the desired peak force. The peak force of 14.3 kips (63.6 kN) from test no. AZPP-2 was set as P_1 and the original embedment depth was 37 in. (940 mm).

$$P_2 = P_1 \left[\frac{ED_{adjusted}}{ED_{original}}\right]^2 \tag{3}$$

where P_1 = Peak Force
P_2 = Desired Peak Force
$ED_{adjusted}$ = Adjusted Embedment
$ED_{original}$ = Original Embedment

The adjusted embedment depth was calculated to be 34.0 in. (864 mm). To reduce the potential for the post to pull out of the ground, the embedment depth was increased by 1 in. (25 mm), thus matching the embedment depth of the SYP posts already used for the AzDOT standard. Therefore, the PP post dimensions for the next round of testing consisted of a diameter of 8½ in. (216 mm), a length of 64 in. (1,626 mm), and an embedment depth of 35 in. (889 mm).

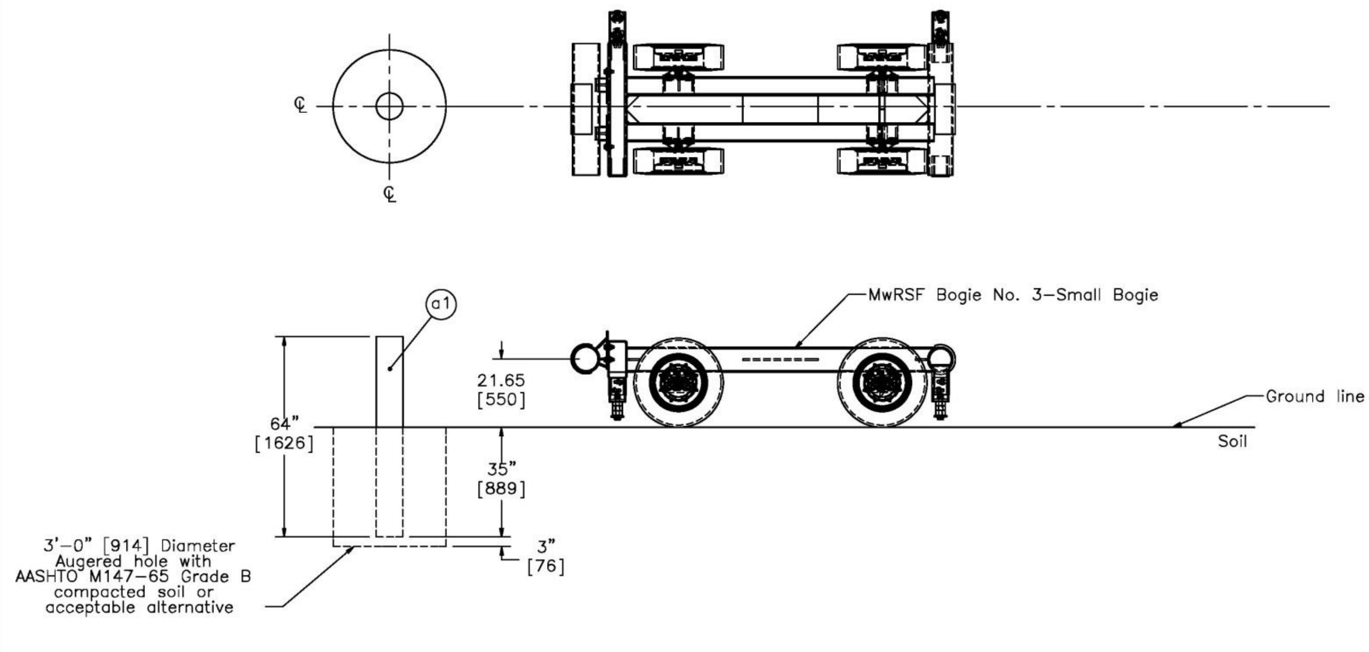
9 DYNAMIC TESTING – ROUND 3 – REVISED PP POSTS

9.1 Scope

Four bogie tests were conducted on 8½-in. (216-mm) diameter round PP posts embedded in soil. In test nos. AZPP-4 through AZPP-7, a 64-in. (1,626-mm) long post was embedded to a depth of 35 in. (889 mm). A compacted, coarse, crushed limestone material was utilized for all tests, as recommended by MASH, [17]. The target impact speed was 20.0 mph (32.2 km/h). The angle of impact was irrelevant; since, a round cross-section does not have a strong or weak axis. Because the rail heights for the AzDOT and U.S. standards differed by less than ¼ in. (6 mm), all posts were impacted at a height of 21.65 in. (550 mm) above the ground line. The bogie testing matrix and the test setup are shown in Figures 32 and 33. Material specifications, mill certifications, and certificates of conformity for the round PP wood posts (test nos. AZPP-4 through AZPP-7) are provided in Appendix B.

It should be noted that the round PP posts were soaked in order to ensure that a saturated moisture condition existed at the time of testing. The saturated moisture condition would result in decreased wood capacity and a conservative post size.

Test Quantity	Post Species	Groundline Diameter in. [mm]	Embedment Depth in. [mm]	Top of Post Height in. [mm]	Post Length in. [mm]	Load Height in. [mm]	Bogie No.	Bogie Speed mph [km/h]
4	PP	8 1/2 [216]	35 [889]	29 [737]	5'–4" [1626]	21.65 [550]	3	20 [32.2]



Notes: (1) For the load height of 21.65" [550], the rear bumper of the small bogie may be used as the impact head.

(2) It was desired that a load height of 21 7/8" [556] be used for the 8 1/2" [216] diameter PP posts. For ease of testing, a 21.65" [550] load height can be used.

(3) Round posts shall be soaked before testing.

MwRSF Midwest Roadside Safety Facility	Ponderosa Pine Post Alternatives	SHEET: 1 of 2
		DATE: 9/11/2012
	Ponderosa Pine Test Setup	DRAWN BY: CWP
	DWG. NAME. PPROUND_round3_R1 / SCALE: 1:44 UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 32. Bogie Testing Matrix and Setup – PP Posts (Round 3)

Item No.	QTY.	Description	Material Specification	Hardware
a1	4	8 1/2" [216] Dia., 64" [1626] Long Ponderosa Pine Post	* see below	–

*PP Round Post Grading Criteria

General:
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 8½–in. (216) diameter guardrail posts will be a minimum of 64 in. (1626) 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 35 in. (889) 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. The ground–line diameter shall be specified by diameter in ¼ in. (6) breaks. The length shall be specified in 12 in. (305) 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 3 in. (76) longer. The diameter of the PP posts shall be 8½ in. (216) at the ground line with an upper limit of 9¼ in. (235).

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. (25).

Shape and Straightness:
All PP 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 1¼ in. (32) 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 exceeding 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.

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3.5 in. (89) or smaller.

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 treated post shall have a minimum sapwood depth of ¾ in. (19), 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.

Decay:
Allowed in knots only.

Holes:
Pin holes 1/16 in. (1) or less are not restricted.

Slope of Grain:
1 in 10.

Compression Wood:
Not allowed in the outer 1 in. (25) or if exceeding ¼ of the radius.

Ring Density:
Ring density shall be at least 6 rings–per–inch, as measured over a 3 in. (76) distance.

MwRSF	Ponderosa Pine Post Alternatives		SHEET: 2 of 2 DATE: 9/11/2012
Midwest Roadside Safety Facility	Bill of Materials		DRAWN BY: CWP
	DWG. NAME. PPROUND_round3_R1	SCALE: NONE UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 33. Bill of Materials – PP Posts (Round 3)

9.2 Test Results

Results from each test are discussed in the following sections. Test results for all accelerometers are provided in Appendix C. The values described herein were calculated from the DTS-SLICE unit.

9.2.1 Test No. AZPP-4

During test no. AZPP-4, the bogie impacted the 8.55-in. (216-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 20.1 mph (32.3 km/h). Initially, the post began to rotate backward. However, by 0.012 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.017 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 7 in. (178 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 34. The post reached a peak force of 17.0 kips (75.6 kN) at 3.6 in. (91 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 54.0 kip-in. (6.1 kJ) before fracture. Time-sequential and post-impact photographs are shown in Figure 35.

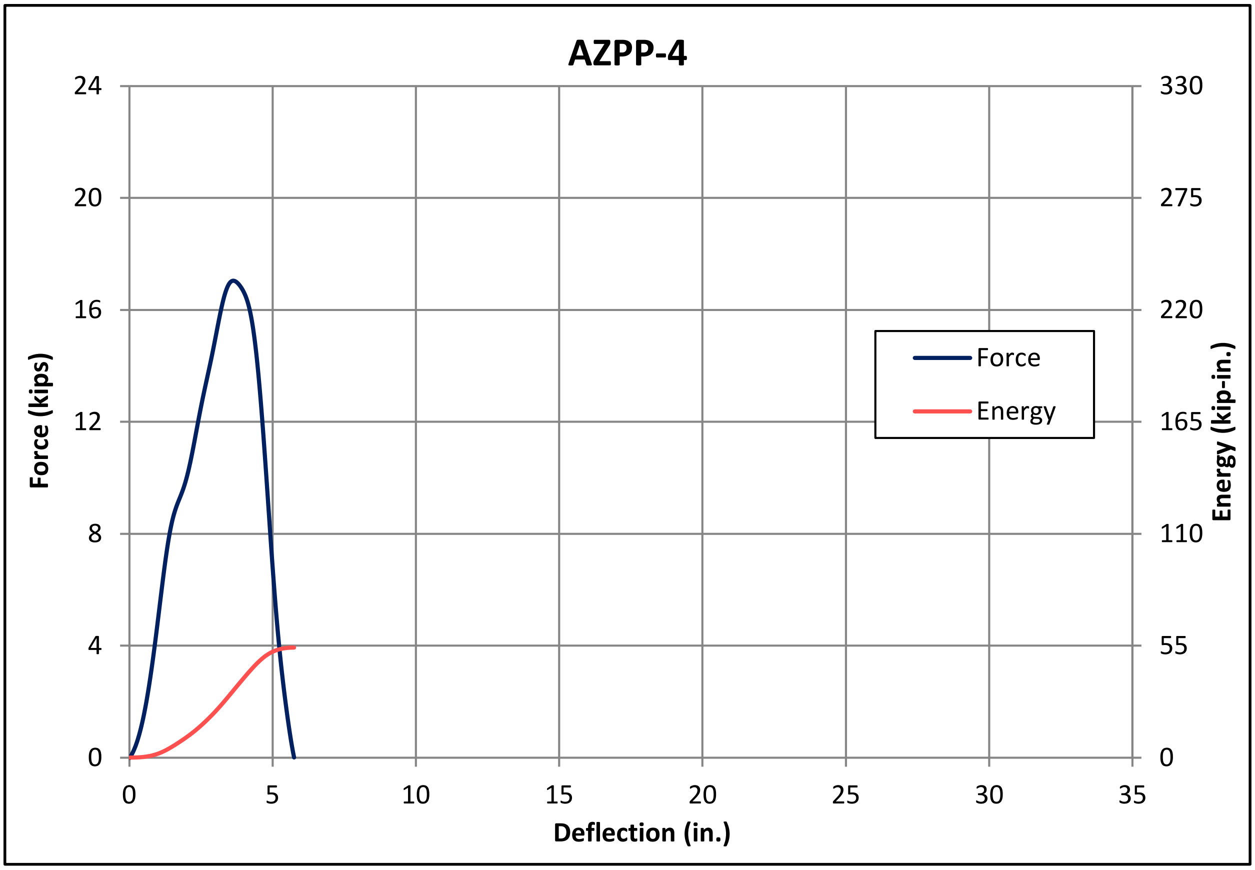


Figure 34. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-4

Figure 35. Time-Sequential and Post-Impact Photographs, Test No. AZPP-4

9.2.2 Test No. AZPP-5

During test no. AZPP-5, the bogie impacted the 8.55-in. (216-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 20.2 mph (32.5 km/h). The post rotated through the soil. The bogie lost contact with the post at a displacement of 28.5 in. (724 mm) as determined from the DTS-SLICE data. The wood post showed no signs of fracture when examined after the impact event.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 36. Early on, the force quickly increased to a peak of 14.2 kips (63.2 kN) at 6.5 in. (165 mm) of deflection. After this peak was attained, the resistive force steadily decreased for the remainder of the impact event. The energy absorbed by the post was 228.0 kip-in. (25.8 kJ) through 20 in. (508 mm) of deflection, and 253.9 kip-in. (28.7 kJ) through 28.5 in. (724 mm) of deflection. Due to technical difficulties, the AOS X-PRI video was not captured. Documentary and post-impact photographs are shown in Figure 37.

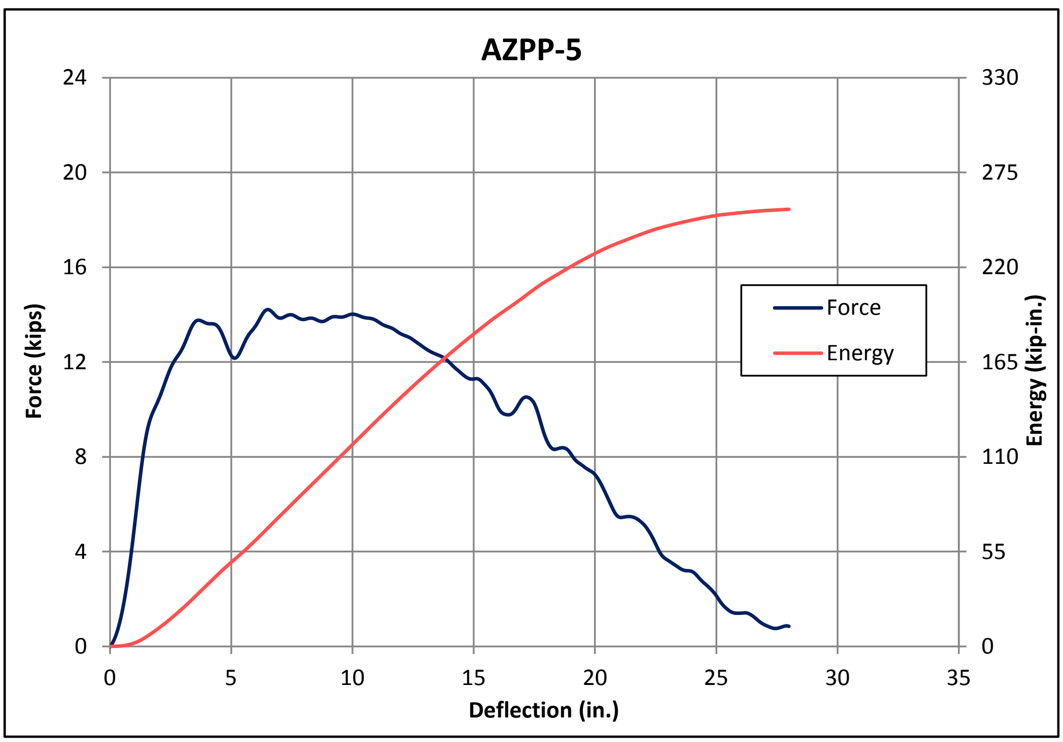


Figure 36. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-5

Figure 37. Documentary and Post-Impact Photographs, Test No. AZPP-5

9.2.3 Test No. AZPP-6

During test no. AZPP-6, the bogie impacted the 8.36-in. (212-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 21.4 mph (34.4 km/h). Initially, the post began to rotate backward. However, by 0.008 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.013 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 7 in. (178 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 38. The post reached a peak force of 12.4 kips (55.2 kN) at 2.9 in. (74 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 34.2 kip-in. (3.9 kJ) by the completion of fracture at 4.9 in. (124 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 39.

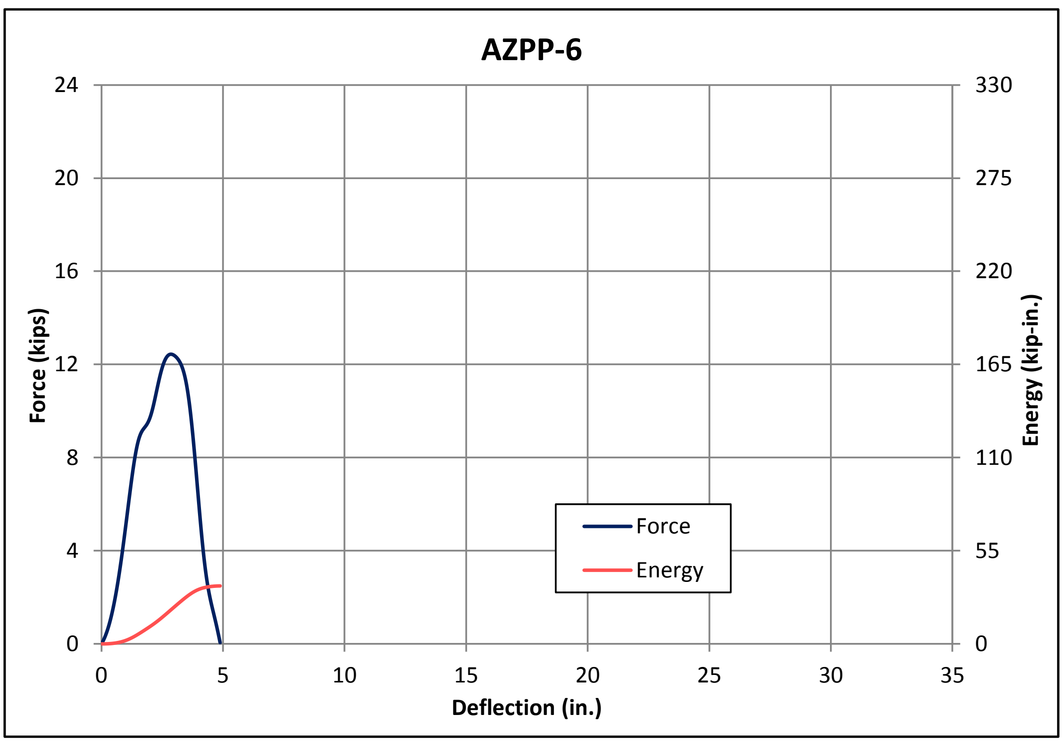
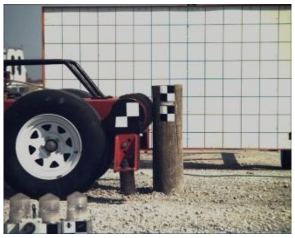


Figure 38. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-6



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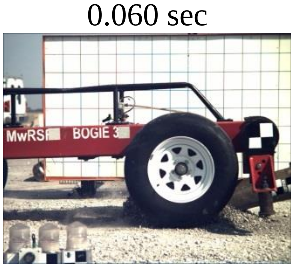

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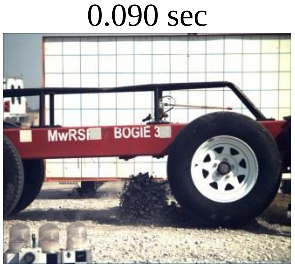

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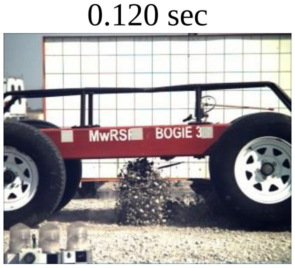

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Figure 39. Time-Sequential and Post-Impact Photographs, Test No. AZPP-6

9.2.4 Test No. AZPP-7

During test no. AZPP-7, the bogie impacted the 8.67-in. (220-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 21.3 mph (34.3 km/h). Initially, the post began to rotate backward. However, by 0.009 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.018 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 5 in. (127 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 40. The post reached a peak force of 16.5 kips (73.4 kN) at 3.4 in. (86 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 63.7 kip-in. (7.2 kJ) by the completion of fracture at 6.5 in. (165 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 41.

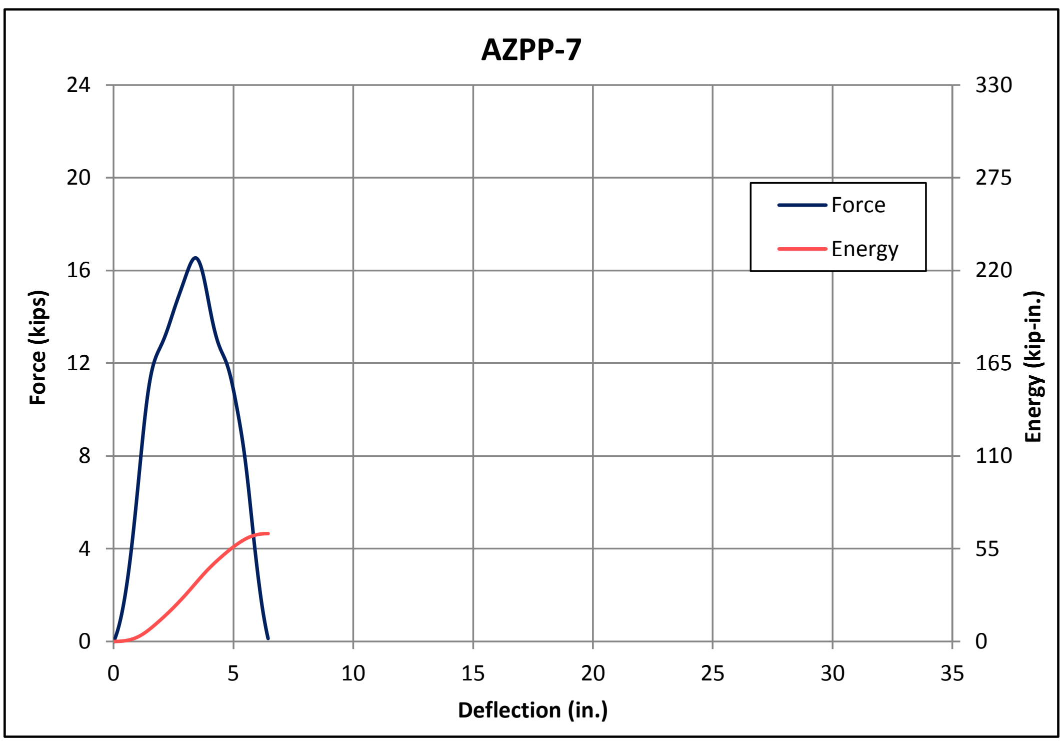

Figure 40. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-7

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Figure 41. Time-Sequential and Post-Impact Photographs, Test No. AZPP-7

9.3 Discussion

Four tests were conducted on PP posts with a targeted ground line diameter of 8½ in. (216 mm) and a post length of 64 in. (1,626 mm) in order to establish the force versus deflection characteristics in soil. The results from the bogie testing matrix are summarized in Table 7. A comparison of the force versus deflection and energy versus deflection curves are shown in Figures 42 and 43, respectively. Three out of the four tests resulted in post fracture, while the post in test no. AZPP-5 rotated through the soil. The peak force (recorded at the onset of fracture) during test nos. AZPP-4, AZPP-6, and AZPP-7 averaged 15.3 kips (68.1 kN). This result is an increase of 16 percent over the average fracture loads obtained from the 8¼-in. (210-mm) diameter PP posts that were tested and evaluated in Round 2. However, the post-soil resistance corresponding to the 8½-in. (216-mm) diameter posts was still too high and likely contributed to premature fracture.

Table 7. Bogie Test Results of 8½-in. (216-mm) Diameter x 64-in (1,626-mm) Long PP Posts, 35-in. (889-mm) Embedment

Test No.	Calculated Post Dia. at Groundline in. (mm)	Calculated Post Dia. 8" below Groundline in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Deflection at Peak Force in. (mm)	Average Force kips (kN)			Absorbed Energy kip-in. (kJ)			Maximum Deflection in. (mm)	Post-Soil Behavior
						@ 10"	@ 15"	@ 20"	@ 10"	@ 15"	@ 20"		
AZPP-4	8.55 (216)	8.49 (216)	20.1 (32.3)	17.0 (75.6)	3.6 (91)	NA	NA	NA	NA	NA	NA	5.7 (145)	Post Fracture
AZPP-5	8.55 (216)	8.53 (217)	20.2 (32.6)	14.2 (63.2)	6.5 (165)	11.8 (52.5)	12.2 (54.3)	11.2 (49.8)	117.3 (13.3)	181.4 (20.5)	228.0 (25.8)	32.3 (820)	Rotation in Soil
AZPP-6	8.36 (212)	8.56 (217)	21.4 (34.4)	12.4 (55.2)	2.9 (74)	NA	NA	NA	NA	NA	NA	4.9 (124)	Post Fracture
AZPP-7	8.67 (220)	8.59 (218)	21.3 (34.3)	16.5 (73.4)	3.4 (86)	NA	NA	NA	NA	NA	NA	6.4 (163)	Post Fracture

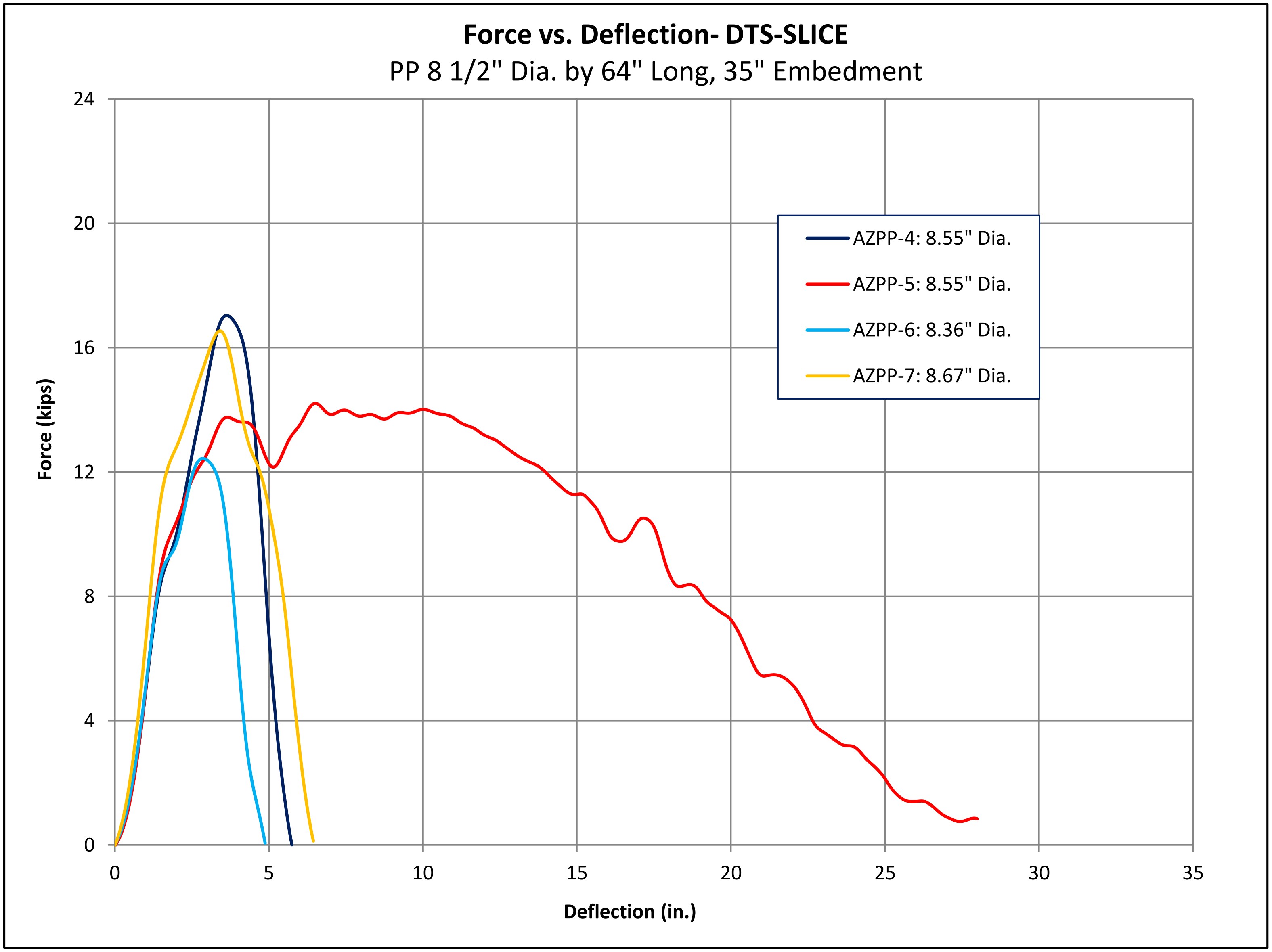


Figure 42. Force vs. Deflection Comparison, Test Nos. AZPP-4 through AZPP-7

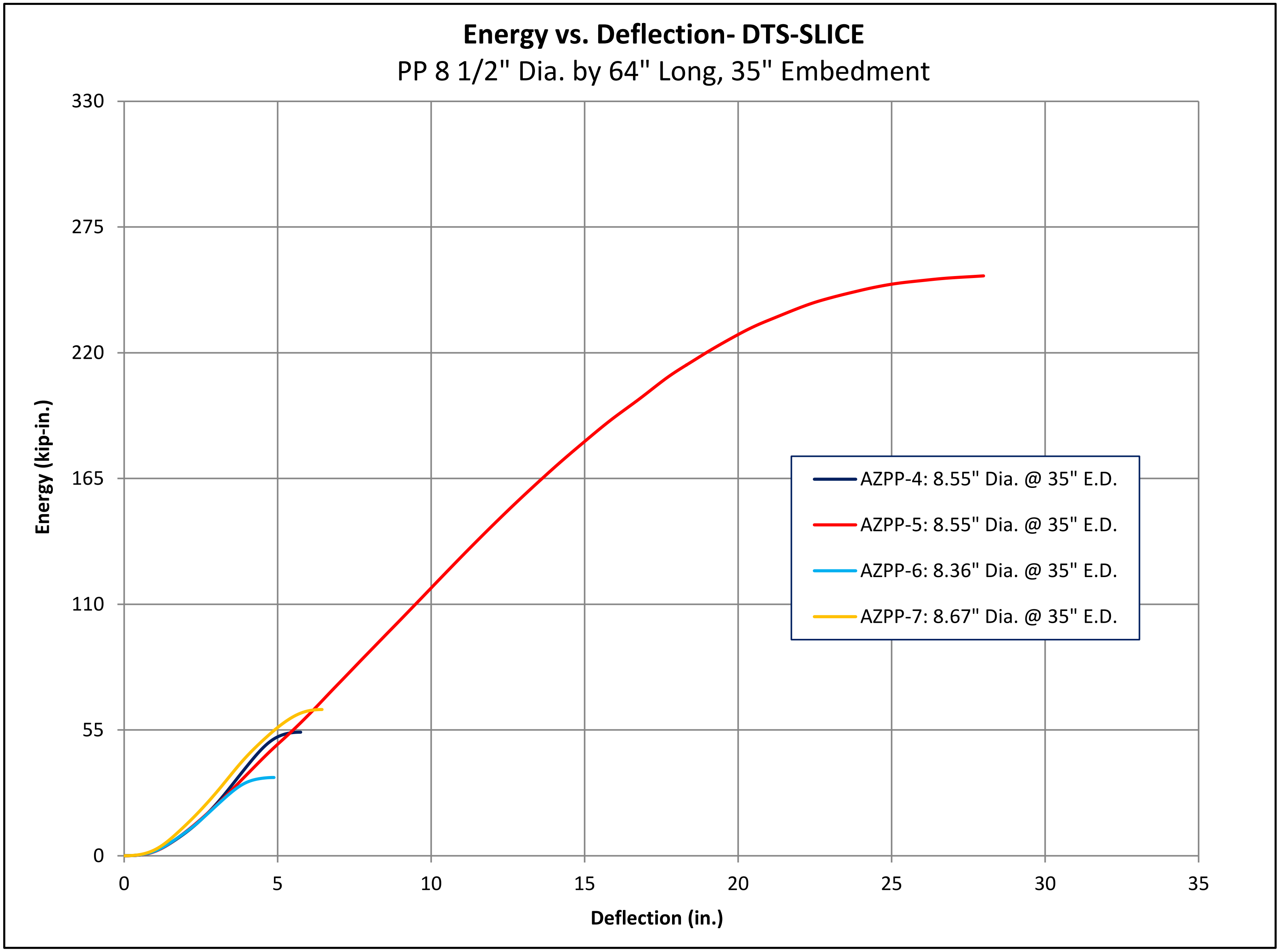


Figure 43. Energy vs. Deflection Comparison, Test Nos. AZPP-4 through AZPP-7

10 FURTHER PP POST SIZE ADJUSTMENT

During the Round 3 bogie testing program, all but one of the 8½-in. (216-mm) diameter PP posts fractured. Therefore, further adjustments to the post dimensions were required. However, the 35-in. (889-mm) embedment depth would not be changed due to the risk of a post with a shallower embedment pulling out of the ground during an impact event. Therefore, only the post diameter would be adjusted.

The ground line diameter for the post used in test no. AZPP-5 (only post that did not fracture in Round 3) was 8.55 in. (217 mm), which was slightly larger than the required diameter of 8½ in. (216 mm). The post used in test no. AZPP-4 had a ground line diameter of 8.55 in. (217 mm), but it fractured. This disparity was most likely caused by wood variability, varying defects in the posts, as well as the diameter within the critical zone. The critical zone was believed to be the location of maximum stress in the post induced by the soil support condition, which was estimated to be approximately 8 in. (203 mm) below ground line and based on observed fracture locations. The post used in test no. AZPP-5 had a slightly larger critical zone diameter [8.53 in. (217 mm)] than used in test no. AZPP-4 [8.49 in. (216 mm)], but it was still smaller than the critical diameter used in test no. AZPP-2 [8.62 in. (219 mm)]. In order to strengthen the post, it was determined that the critical zone diameter should be increased to a minimum of 8¾ in. (222 mm). Therefore, the PP post dimensions for the next round of testing consisted of a diameter of 8¾ in. (222 mm), a length of 64 in. (1,626 mm), and an embedment depth of 35 in. (889 mm).

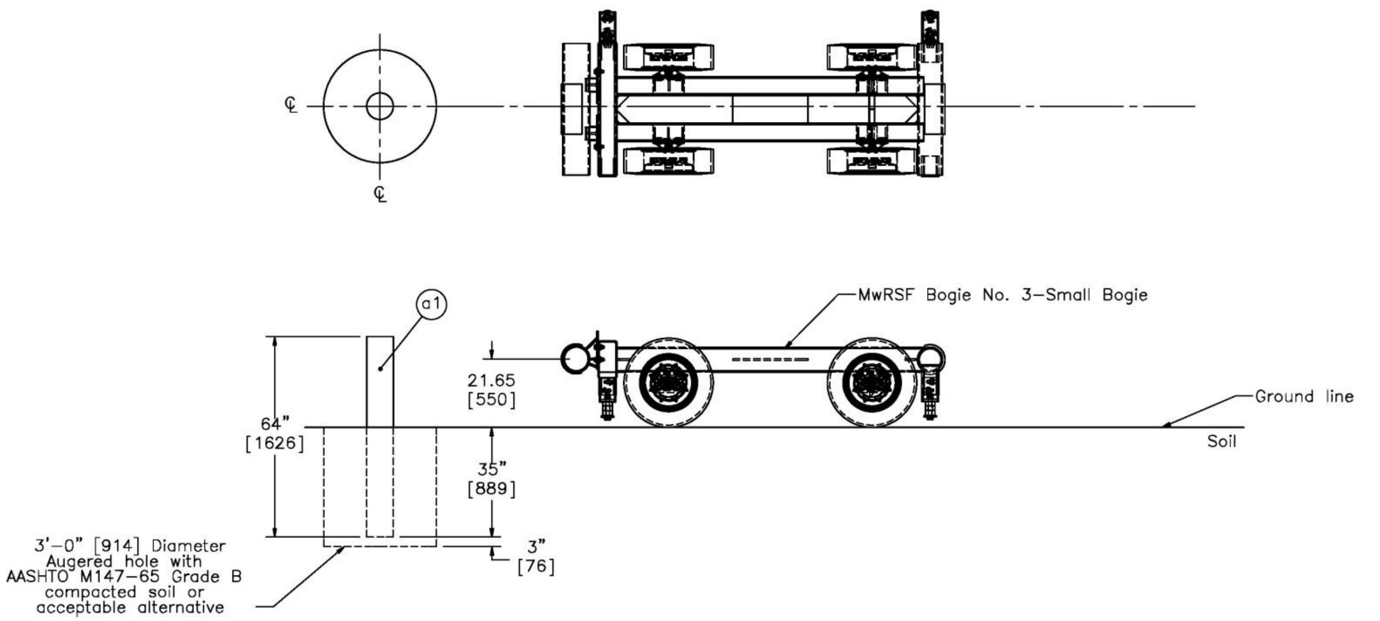
11 DYNAMIC TESTING – ROUND 4 – REVISED PP POSTS

11.1 Scope

Two bogie tests were conducted on 8¾-in. (222-mm) diameter round PP posts embedded in soil. In test nos. AZPP-8 and AZPP-9, a 64-in. (1,626-mm) long post was embedded to a depth of 35 in. (889 mm). A compacted, coarse, crushed limestone material was utilized for all tests, as recommended by MASH [17]. The target impact speed was 20.0 mph (32.2 km/h). The angle of impact was irrelevant; since, a round cross-section does not have a strong or weak axis. Because the rail heights for both the AzDOT and U.S. standards differed by less than ¼ in. (6 mm), all posts were impacted at a height of 21.65 in. (550 mm) above the ground line. The bogie testing matrix and the test setup are shown in Figures 44 and 45. Material specifications, mill certifications, and certificates of conformity for the round PP wood posts (test nos. AZPP-8 and AZPP-9) are provided in Appendix B.

It should be noted that the round PP posts were soaked in order to ensure that a saturated moisture condition existed at the time of testing. The saturated moisture condition would result in decreased wood capacity and a conservative post size.

Test Quantity	Post Species	Groundline Diameter in. [mm]	Embedment Depth in. [mm]	Top of Post Height in. [mm]	Post Length in. [mm]	Load Height in. [mm]	Bogie No.	Bogie Speed mph [km/h]
2	PP	8 3/4 [222]	35 [889]	29 [737]	5'-4" [1626]	21.65 [550]	3	20 [32.2]



Notes: (1) For the load height of 21.65" [550], the rear bumper of the small bogie may be used as the impact head.

(2) It was desired that a load height of 21 7/8" [556] be used for the 8 3/4" [222] diameter PP posts. For ease of testing, a 21.65" [550] load height can be used.

(3) Round posts shall be soaked before testing and allowed to air dry for one day.

(4) The critical zone diameter, measured 37" [940] from the top of post, shall be greater than or equal to 8 3/4" [222]. It may be acceptable for the ground line diameter to measure greater than or equal to 8 5/8" [219] as long as critical zone diameter is met.

Midwest Roadside Safety Facility

Ponderosa Pine Post Alternatives – Round 4

Ponderosa Pine Test Setup

SHEET: 1 of 2
DATE: 11/12/2012
DRAWN BY: CWP
DWG. NAME. PPROUND_round4_R1
SCALE: 1:44
UNITS: in.[mm]
REV. BY: RKF

Figure 44. Bogie Testing Matrix and Setup – PP Posts (Round 4)

Item No.	QTY.	Description	Material Specification	Hardware
a1	2	8 3/4" [222] Dia., 64" [1626] Long Ponderosa Pine Post	* see below	–

*PP Round Post Grading Criteria

General:
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 8¾–in. (222) diameter guardrail posts will be a minimum of 64 in. (1626) 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 35 in. (889) 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. The ground–line diameter shall be specified by diameter in ¼ in. (6) breaks. The length shall be specified in 12 in. (305) 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 3 in. (76) longer. The diameter of the PP posts shall be 8¾ in. (222) at the ground line with an upper limit of 9½ in. (241).

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. (25).

Shape and Straightness:
All PP 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 1¼ in. (32) 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 exceeding 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.

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3.5 in. (89) or smaller.

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 treated post shall have a minimum sapwood depth of ¾ in. (19), 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.

Decay:
Allowed in knots only.

Holes:
Pin holes 1/16 in. (1) or less are not restricted.

Slope of Grain:
1 in 10.

Compression Wood:
Not allowed in the outer 1 in. (25) or if exceeding ¼ of the radius.

Ring Density:
Ring density shall be at least 6 rings–per–inch, as measured over a 3 in. (76) distance.

Midwest Roadside Safety Facility	Ponderosa Pine Post Alternatives – Round 4		SHEET: 2 of 2
			DATE: 11/12/2012
	Bill of Materials		DRAWN BY: CWP
	DWG. NAME. PPROUND_round4_R1	SCALE: NONE UNITS: in.[mm]	REV. BY: RKF

Figure 45. Bill of Materials – PP Posts (Round 4)

11.2 Test Results

Results from each test are discussed in the following sections. Test results for all accelerometers are provided in Appendix C. The values described herein were calculated from the DTS-SLICE unit.

11.2.1 Test No. AZPP-8

During test no. AZPP-8, the bogie impacted the 8.71-in. (221-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 21.1 mph (34.0 km/h). The post rotated through the soil, and the bogie overrode the post at a displacement of 28.9 in. (734 mm), as determined from the DTS-SLICE data. The wood post showed no signs of fracture when examined after the impact event.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 46. Early on, the force quickly increased to a peak of 20.5 kips (91.2 kN) at 6.5 in. (165 mm) of deflection. After this peak was attained, the resistive force steadily decreased for the remainder of the impact event. The energy absorbed by the post was 289.8 kip-in. (32.7 kJ) through 20 in. (508 mm) of deflection, and 313.5 kip-in. (35.4 kJ) through 28.9 in. (734 mm). Time-sequential and post-impact photographs are shown in Figure 47.

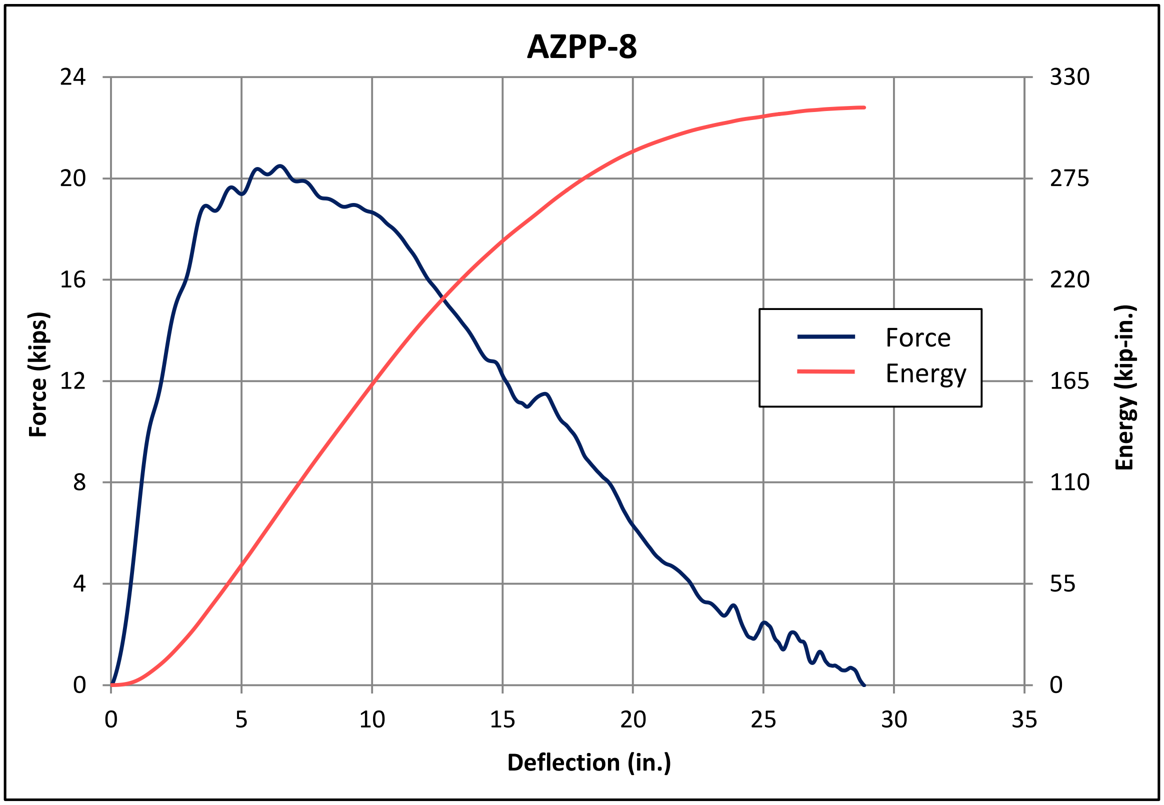


Figure 46. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-8

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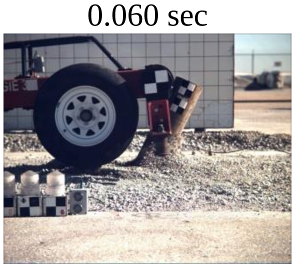

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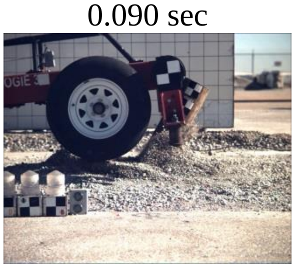

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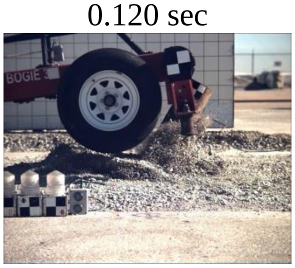

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Figure 47. Time-Sequential and Post-Impact Photographs, Test No. AZPP-8

11.2.2 Test No. AZPP-9

During test no. AZPP-9, the bogie impacted the 8.75-in. (222-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 20.7 mph (33.3 km/h). Initially, the post began to rotate backward. However, by 0.010 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.014 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 7 in. (178 mm) below the ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 48. The post reached a peak force of 9.2 kips (40.9 kN) at 3.5 in. (89 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 27.6 kip-in. (3.1 kJ) at the completion of fracture. Time-sequential and post-impact photographs are shown in Figure 49.

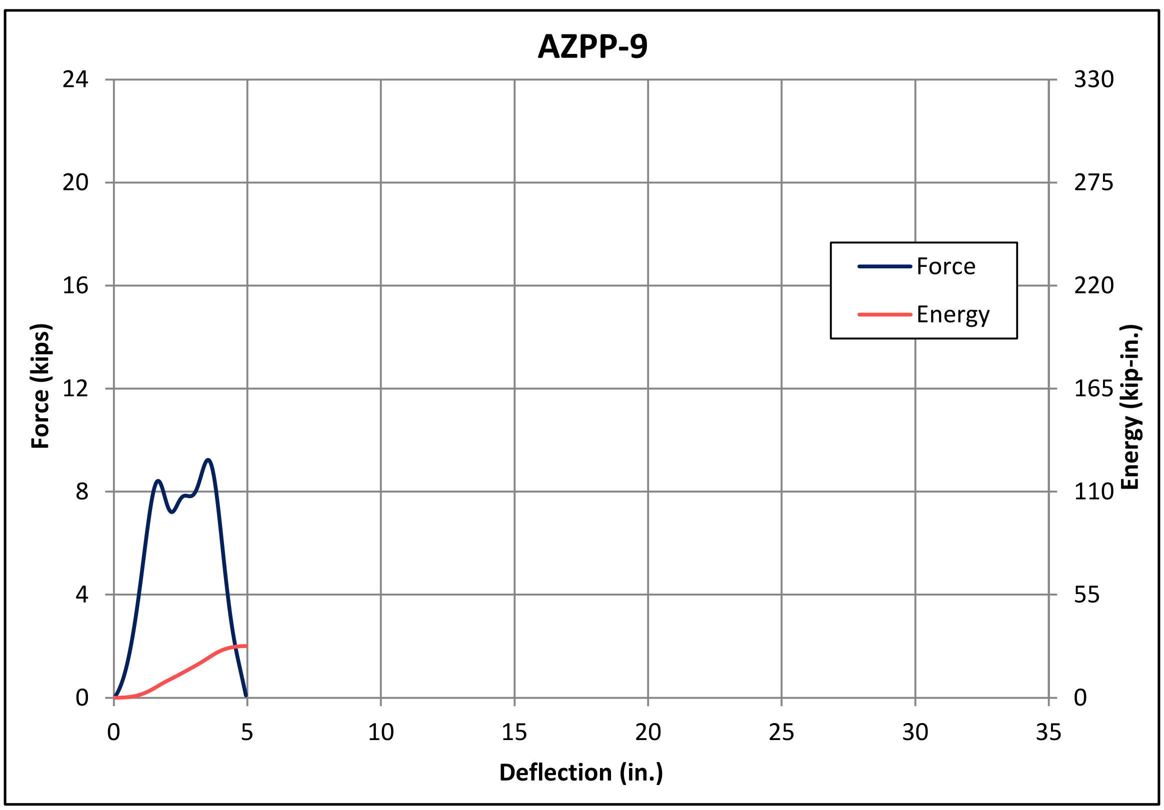

Figure 48. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-9

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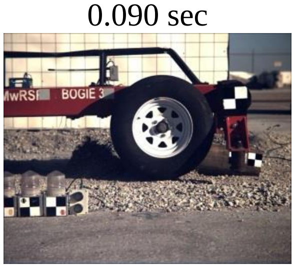

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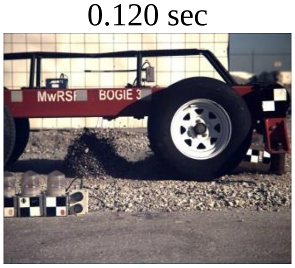

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Figure 49. Time-Sequential and Post-Impact Photographs, Test No. AZPP-9

11.3 Discussion

Two tests were conducted on PP posts with a targeted ground line diameter of 8¾-in. (222-mm) diameter and a post length of 64-in. (1,626-mm) in order to establish the force versus deflection characteristics in soil. The results from the bogie testing matrix are summarized in Table 8. A comparison of force versus deflection and energy versus deflection curves are shown in Figures 50 and 51, respectively. One post fractured in test no. AZPP-9, while one post rotated in soil for test no. AZPP-8. Interestingly, the AZPP-9 post fractured under a load significantly lower than any of the previous tests on round PP posts. Upon further inspection, multiple knots were found near the critical section of the post that may have contributed to premature fracture.

Table 8. Bogie Test Results of 8¾-in. (222-mm) Diameter x 64-in (1,626-mm) Long PP Posts, 35-in. (889-mm) Embedment

Test No.	Calculated Post Dia. at Groundline in.(mm)	Calculated Post Dia. 8" below Groundline in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Deflection at Peak Force in. (mm)	Average Force kips (kN)			Absorbed Energy kip-in. (kJ)			Maximum Deflection in. (mm)	Post-Soil Behavior
						@ 10"	@ 15"	@ 20"	@ 10"	@ 15"	@ 20"		
AZPP-8	8.71 (221)	8.83 (224)	21.1 (34.0)	20.5 (91.2)	6.5 (165)	16.6 (73.8)	16.1 (71.6)	13.7 (60.9)	163.5 (18.5)	241.2 (27.3)	289.8 (32.7)	28.8 (732)	Rotation in Soil
AZPP-9	8.75 (222)	8.87 (225)	20.7 (33.3)	9.2 (40.9)	3.5 (89)	NA	NA	NA	NA	NA	NA	4.9 (124)	Post Fracture

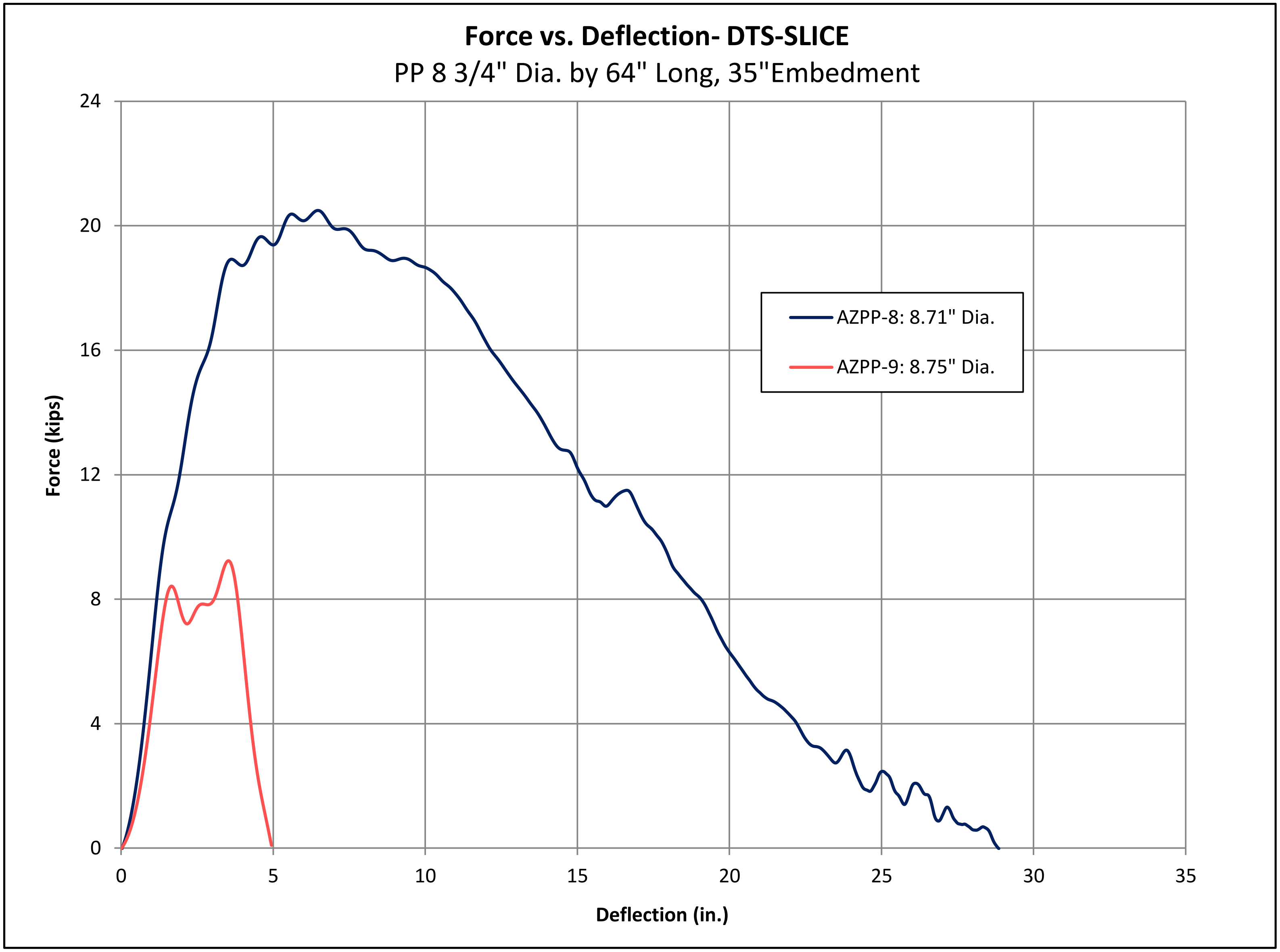


Figure 50. Force vs. Deflection Comparison, Test Nos. AZPP-8 and AZPP-9

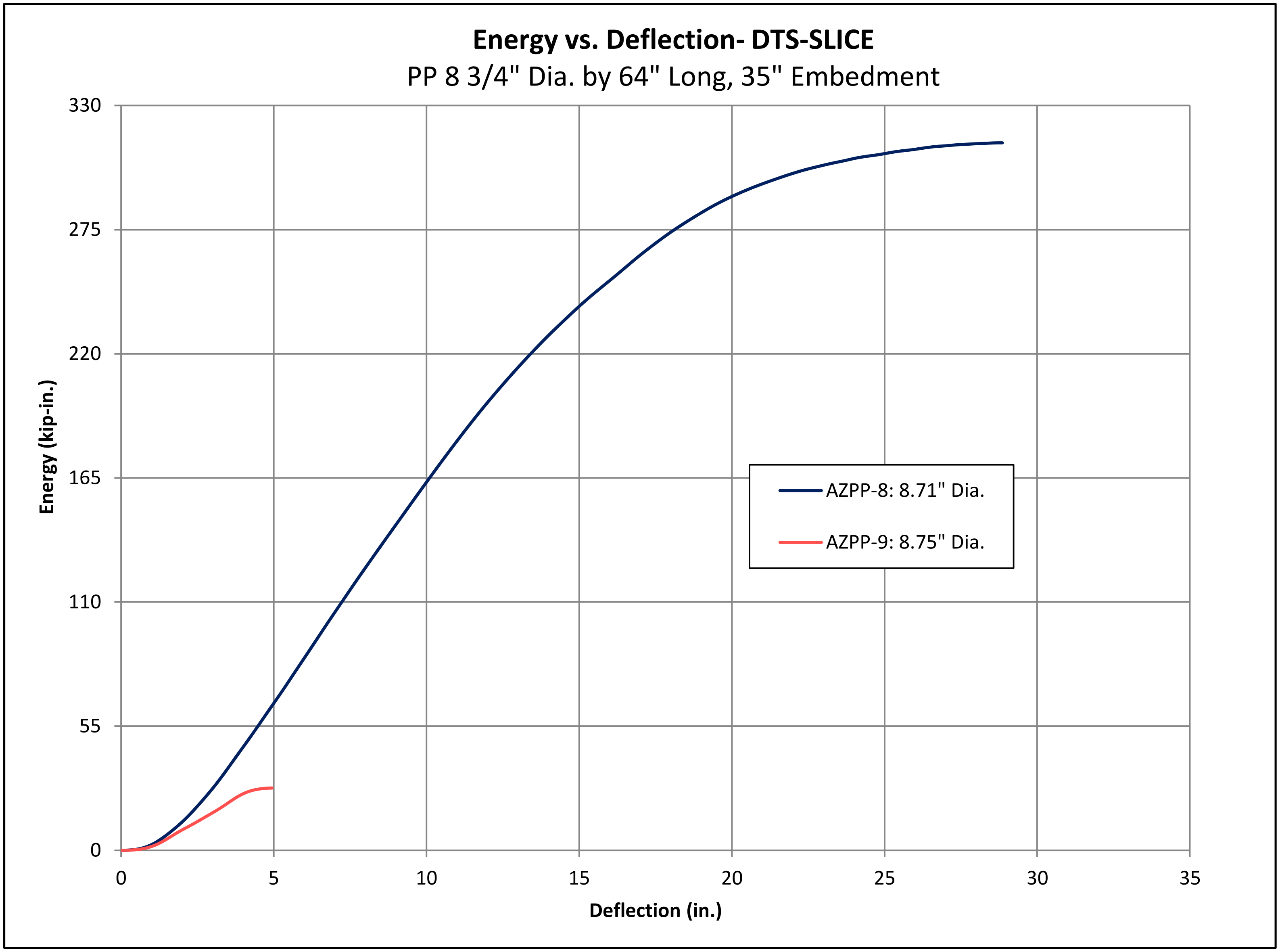


Figure 51. Energy vs. Deflection Comparison, Test Nos. AZPP-8 and AZPP-9

12 EVALUATION OF POST SELECTION CRITERIA

12.1 Examination of Fractured Posts

Thus far, test nos. AZPP-1 through AZPP-9 had provided inconsistent results due to post fracture at different diameters and at lower loads than expected. As such, a specific post diameter for PP posts was not selected. Wood variability was believed to contribute to unexpected results. To further explore this issue, Mr. David Kretschmann of the Forest Products Laboratory, along with Mr. Randy Nicol of Arizona Log & TimberWorks and Mr. Bill Greenwood of the Northern Arizona Wood Products Association, visited MwRSF to examine the PP wood posts and failure surfaces. Mr. Kretschmann inspected and evaluated each post and documented any grading concerns. The memorandum summarizing the post review and inspection, including pictures of each fractured post, is provided in Appendix D.

After examination, it was evident that four of the six fractured PP posts had critical grading problems. The posts used in test nos. AZPP-3 and AZPP-4 displayed only moderate grading concerns, such as slope of grain and an off-centered wood core, as listed in Table 9. The remaining posts had more severe grading issues that reduced the post strength, thus allowing the posts to fracture at lower forces than expected. Test nos. AZPP-1 and AZPP-7 used posts with large juvenile wood cores, which fractured more easily due to a lower strength than found in mature wood. The post used in test no. AZPP-6 showed severe slope of grain, deviating from the desired vertical grain lines from the bottom of post to top of post. Lastly, test no. AZPP-9 was performed on a post that had a decayed core, thus reducing its strength considerably.

Once again, several significant grading issues were observed in four PP posts. As such, it was determined that better adherence to the existing PP grading rules would be needed in order to ensure that quality PP posts were used in any future testing program as well as in actual W-beam guardrail systems. It should be noted that the PP grading rules remained the same as those previously-provided to Arizona Log & TimberWorks.

Table 9. Grading Issues with Fractured Posts

Test No.	Grading Issue
AZPP-1	Ring shake was present, large juvenile wood core
AZPP-3	Ring shake was present, some slope of grain
AZPP-4	Off-centered large juvenile wood core
AZPP-6	Severe slope of grain
AZPP-7	Severely off-centered large juvenile wood core
AZPP-9	Decayed heart as indicated by substantial wound and large bark inclusion

12.2 Second Post Sampling

Based on the findings of the FPL post inspection and evaluation, a new sample of PP posts with more rigorous inspection and grading was deemed necessary before continuing the dynamic component testing program. Therefore, personnel from Arizona Log & TimberWorks selected a new group of PP posts after closely monitoring those grading violations from the first shipment of round PP posts. Thus, 12 new PP posts were acquired with ground line diameters ranging between 8¼ to 8⅞ in. (210 to 225 mm).

13 DYNAMIC TESTING – ROUND 5 – PP POSTS

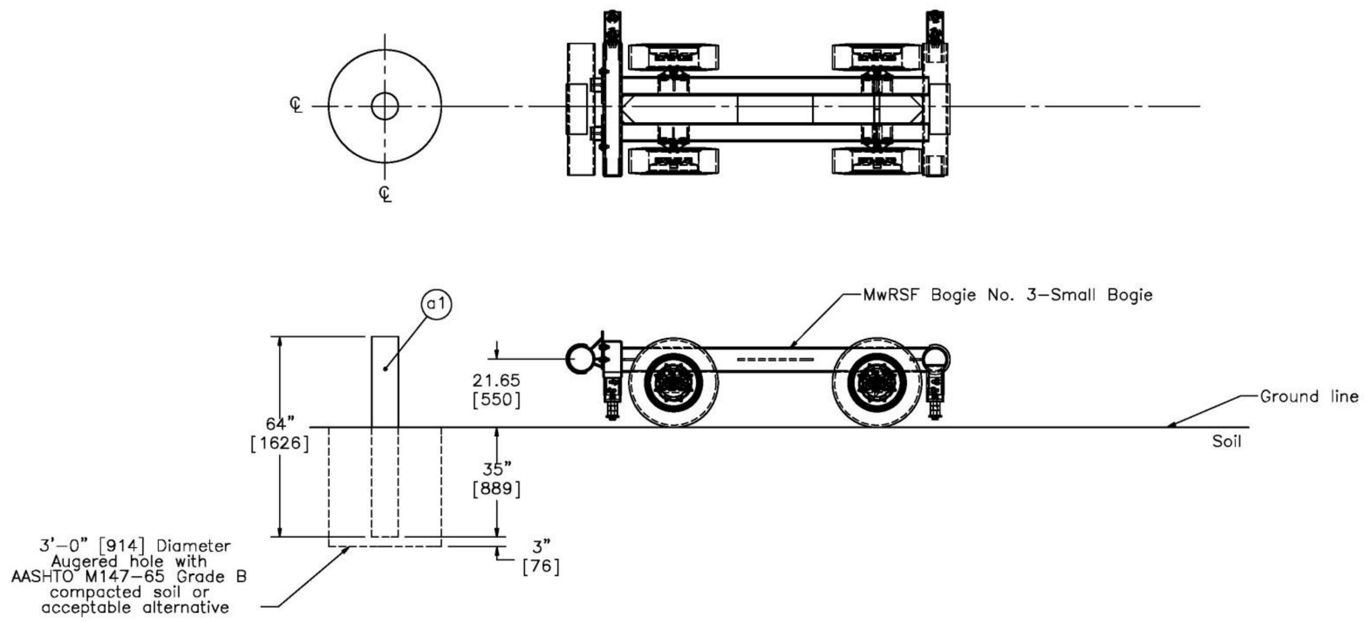
13.1 Scope

Two bogie tests were conducted on 8½-in. (216-mm) diameter round PP posts embedded in soil. An 8½-in. (216-mm) diameter PP post was selected for re-testing; since, it was believed that this size would produce acceptable results with adherence to the existing grading rules.

For test nos. AZPP-10 and AZPP-11, a 64-in. (1,626-mm) long post was embedded to a depth of 35 in. (889 mm). A compacted, coarse, crushed limestone material was utilized for all tests, as recommended by MASH [17]. The target impact speed was 20.0 mph (32.2 km/h). The angle of impact was irrelevant; since, a round cross-section does not have a strong or weak axis. Because the rail heights for both the AzDOT and U.S. standards differed by less than ¼ in. (6 mm), the posts were impacted at a height of 21.65 in. (550 mm) above the ground line. The bogie testing matrix and the test setup are shown in Figures 52 and 53. Material specifications, mill certifications, and certificates of conformity for the round PP wood posts (test nos. AZPP-10 and AZPP-11) are provided in Appendix B.

It should be noted that the round PP posts were soaked in order to ensure that a saturated moisture condition existed at the time of testing. The saturated moisture condition would result in decreased wood capacity and a conservative post size.

Test Quantity	Post Species	Groundline Diameter in. [mm]	Embedment Depth in. [mm]	Top of Post Height in. [mm]	Post Length in. [mm]	Load Height in. [mm]	Bogie No.	Bogie Speed mph [km/h]
2	PP	8 1/2 [216]	35 [889]	29 [737]	5'–4" [1626]	21.65 [550]	3	20 [32.2]



Notes: (1) For the load height of 21.65" [550], the rear bumper of the small bogie may be used as the impact head.

(2) It was desired that a load height of 21 7/8" [556] be used for the 8 1/2" [216] diameter PP posts. For ease of testing, a 21.65" [550] load height can be used.

(3) Round posts shall be soaked before testing and allowed to air dry for one day.

(4) The critical zone diameter, measured 37" [940] from the top of post, shall be greater than or equal to 8 1/2" [216]. It may be acceptable for the ground line diameter to measure greater than or equal to 8 3/8" [213] as long as critical zone diameter is met.

MwRSF	Ponderosa Pine Post Alternatives – Round 5		SHEET: 1 of 2 / DATE: 5/6/2013
Midwest Roadside Safety Facility	Ponderosa Pine Test Setup		DRAWN BY: CWP
	DWG. NAME. PPROUND_round5_R0	SCALE: 1:44 UNITS: in.[mm]	REV. BY:

Figure 52. Bogie Testing Matrix and Setup – PP Posts (Round 5)

Item No.	QTY.	Description	Material Specification	Hardware
a1	2	8 1/2" [216] Dia., 64" [1626] Long Ponderosa Pine Post	* see below	–

*PP Round Post Grading Criteria

General:
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 8½–in. (216) diameter guardrail posts will be a minimum of 64 in. (1626) 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 35 in. (889) 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. The ground–line diameter shall be specified by diameter in ¼ in. (6) breaks. The length shall be specified in 12 in. (305) 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 3 in. (76) longer. The diameter of the PP posts shall be 8½ in. (216) at the ground line with an upper limit of 9½ in. (241).

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. (25).

Shape and Straightness:
All PP 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 1¼ in. (32) 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 exceeding 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.

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3.5 in. (89) or smaller.

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 treated post shall have a minimum sapwood depth of ¾ in. (19), 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.

Decay:
Allowed in knots only.

Holes:
Pin holes 1/16 in. (1) or less are not restricted.

Slope of Grain:
1 in 10.

Compression Wood:
Not allowed in the outer 1 in. (25) or if exceeding ¼ of the radius.

Ring Density:
Ring density shall be at least 6 rings–per–inch, as measured over a 3 in. (76) distance.

MwRSF	Ponderosa Pine Post Alternatives – Round 5		SHEET: 2 of 2 / DATE: 5/6/2013
Midwest Roadside Safety Facility	Bill of Materials		DRAWN BY: CWP
	DWG. NAME. PPROUND_round5_R0	SCALE: NONE / UNITS: in.[mm]	REV. BY:

Figure 53. Bill of Materials – PP Posts (Round 5)

13.2 Test Results

Results from each test are discussed in the following sections. Test results for all accelerometers are provided in Appendix C. The values described herein were calculated from the DTS-SLICE unit.

13.2.1 Test No. AZPP-10

During test no. AZPP-10, the bogie impacted the 8½-in. (216-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 22.1 mph (35.6 km/h). Initially, the post began to rotate backward. However, by 0.0082 seconds, the post began to fracture. The top of the post continued to rotate backward until the bogie lost contact with it at 0.072 seconds and overrode it. Upon post-test examination, the post was found to have fractured approximately 5.0 in. (127 mm) below ground line.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 54. The post reached a peak force of 15.0 kips (66.7 kN) at 3.1 in. (79 mm) of deflection. At this point, the post began to fracture, and the resistive force rapidly declined. The energy absorbed by the post was 44.6 kip-in. (5.0 kJ) by the completion of post fracture. Time-sequential and post-impact photographs are shown in Figure 55.

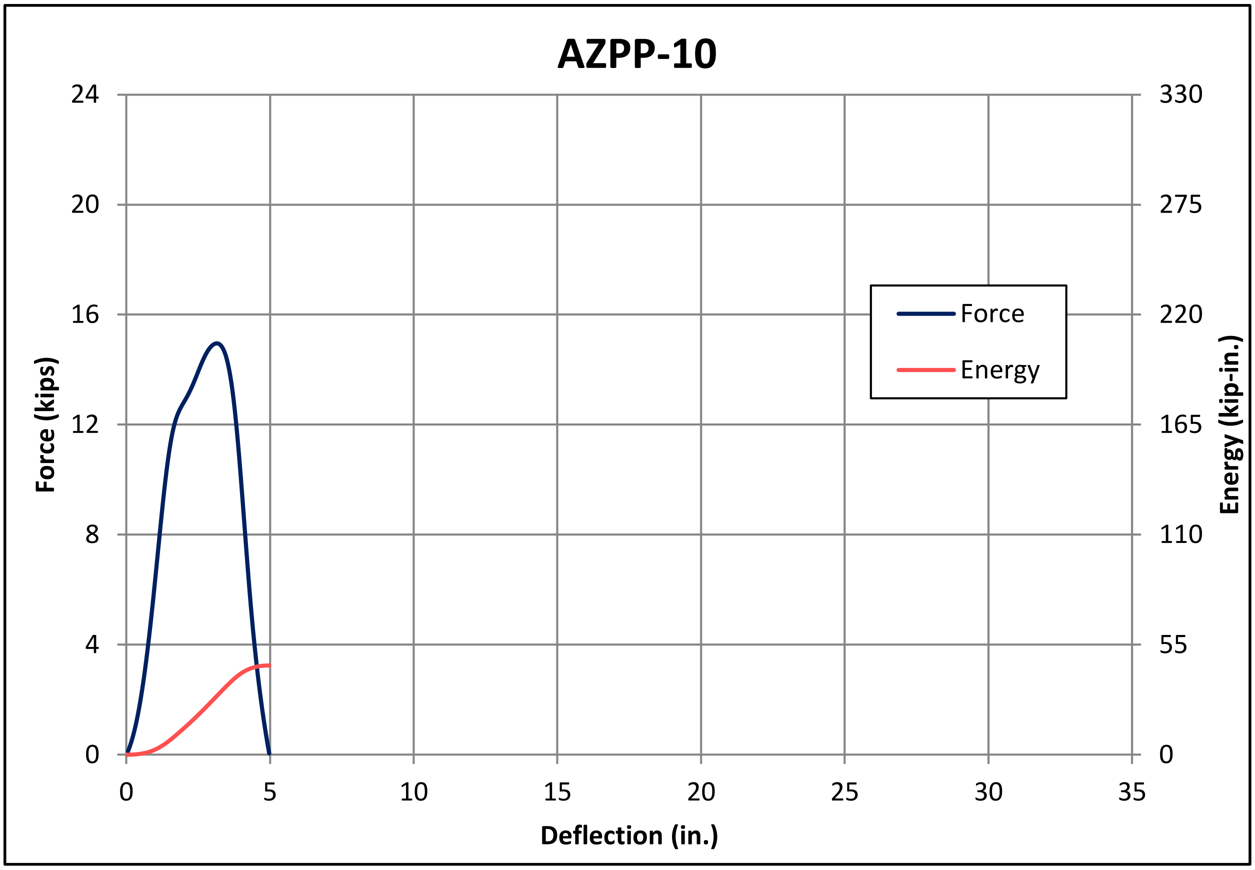


Figure 54. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-10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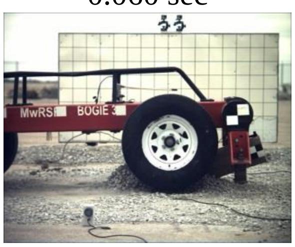
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Figure 55. Time-Sequential and Post-Impact Photographs, Test No. AZPP-10

13.2.2 Test No. AZPP-11

During test no. AZPP-11, the bogie impacted the 8½-in. (216-mm) diameter x 64-in. (1,626-mm) long PP wood post with a 35 in. (889 mm) embedment depth at a speed of 21.9 mph (35.2 km/h). The post rotated through the soil. The bogie overrode the post at a displacement of 31.3 in. (795 mm), as determined from the DTS-SLICE data. The wood post showed no signs of fracture when examined after the impact event.

Force vs. deflection and energy vs. deflection curves from the DTS-SLICE accelerometer data are shown in Figure 56. Early on, the force quickly increased to a peak of 15.4 kips (68.5 kN) at 4.9 in. (124 mm) of deflection. After this peak was attained, the resistive force steadily decreased for the remainder of the impact event. The energy absorbed by the post was 215.7 kip-in. (24.4 kJ) through 20 in. (508 mm) of deflection and 235.0 kip-in. (26.6 kJ) through 31.3 in. (795 mm). Time-sequential and post-impact photographs are shown in Figure 57.

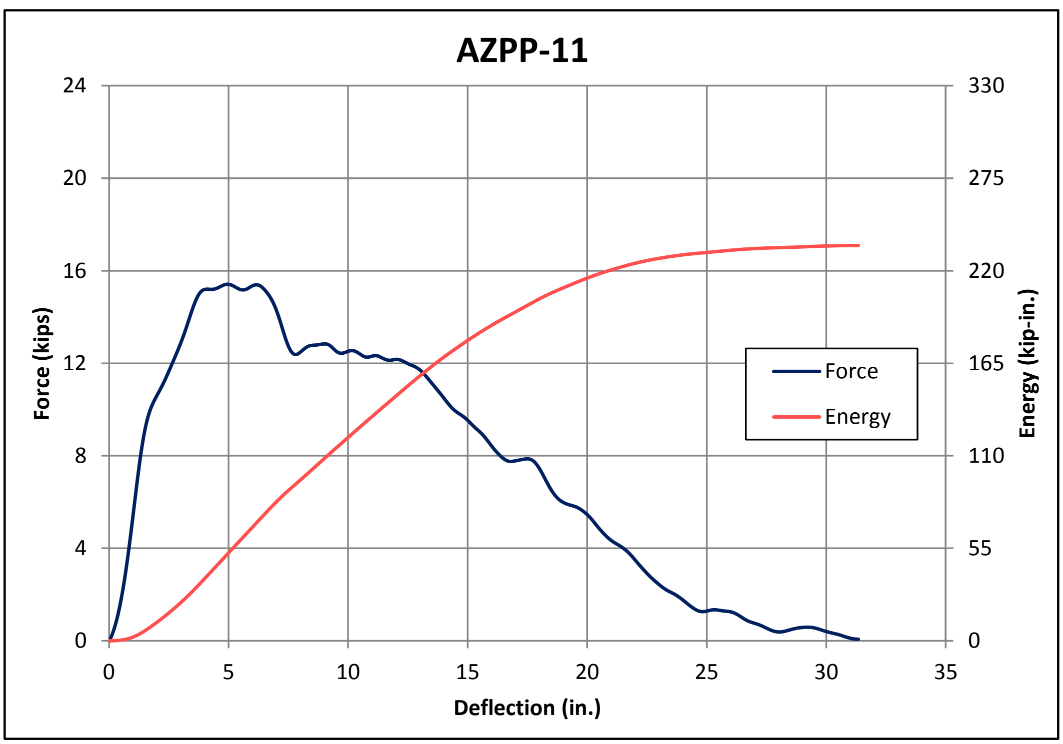

Figure 56. Force vs. Deflection and Energy vs. Deflection, Test No. AZPP-11

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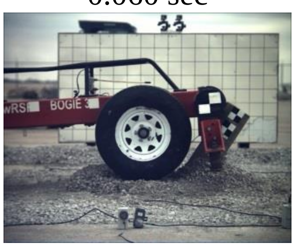

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Figure 57. Time-Sequential and Post-Impact Photographs, Test No. AZPP-11

13.3 Discussion

Two tests were conducted on PP posts with a targeted ground line diameter of 8½ in. (216 mm) and a post length of 64 in. (1,626 mm) in order to establish the force versus deflection characteristics in soil. The results from the bogie testing matrix are summarized in Table 8. A comparison of the force versus deflection and energy versus deflection curves are shown in Figures 58 and 59, respectively. One post fractured in test no. AZPP-10, while one post rotated in soil for test no. AZPP-11. Both posts were subjected to similar peak forces of about 15.0 kips (66.7 kN). For test no. AZPP-11, the energy absorbed by soil rotation was within 5% of the energy absorbed in test no. AZPP-5. In the later test, the 8½-in. (216-mm) diameter post also did not fracture and obtained displacements of 15 in. (318 mm) and 20 in. (508 mm).

Table 10. Bogie Test Results of 8½-in. (216-mm) Diameter x 64-in (1,626-mm) long PP posts, 35-in. (889-mm) Embedment

Test No.	Calculated Post Dia. at Groundline in. (mm)	Calculated Post Dia. 8" below Groundline in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Deflection at Peak Force in. (mm)	Average Force kips (kN)			Absorbed Energy kip-in. (kJ)			Maximum Deflection in. (mm)	Post-Soil Behavior
						@ 10"	@ 15"	@ 20"	@ 10"	@ 15"	@ 20"		
AZPP-10	8.48 (215)	8.48 (215)	22.1 (35.6)	15.0 (66.7)	3.1 (79)	NA	NA	NA	NA	NA	NA	5.0 (127)	Post Fracture
AZPP-11	8.44 (214)	8.36 (212)	21.9 (35.2)	15.4 (68.5)	4.9 (124)	12.2 (54.3)	11.9 (52.9)	10.6 (47.2)	121.1 (13.7)	178.7 (20.2)	215.7 (24.4)	31.3 (795)	Rotation in Soil

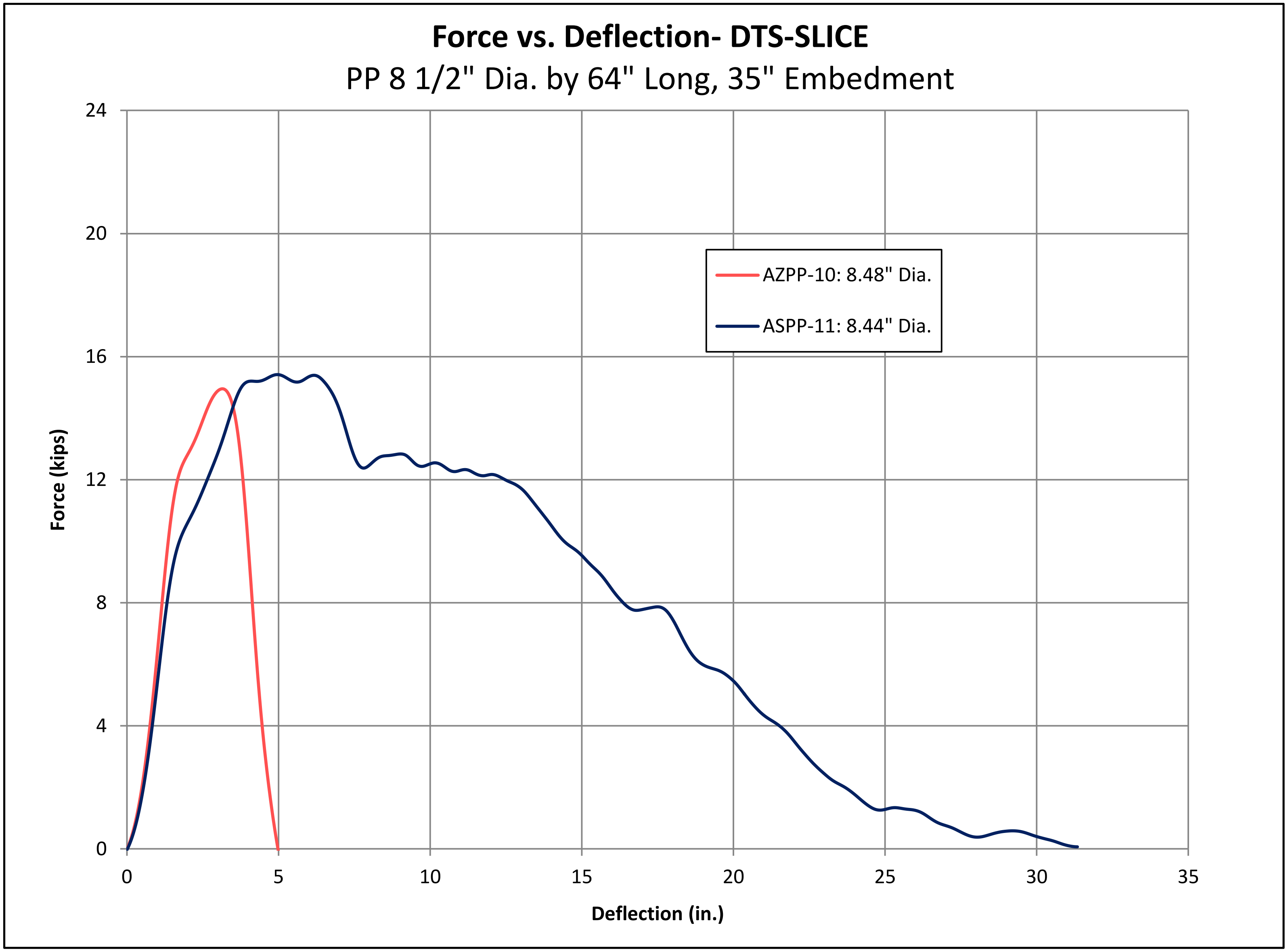

Figure 58. Force vs. Deflection Comparison, Test Nos. AZPP-10 and AZPP-11

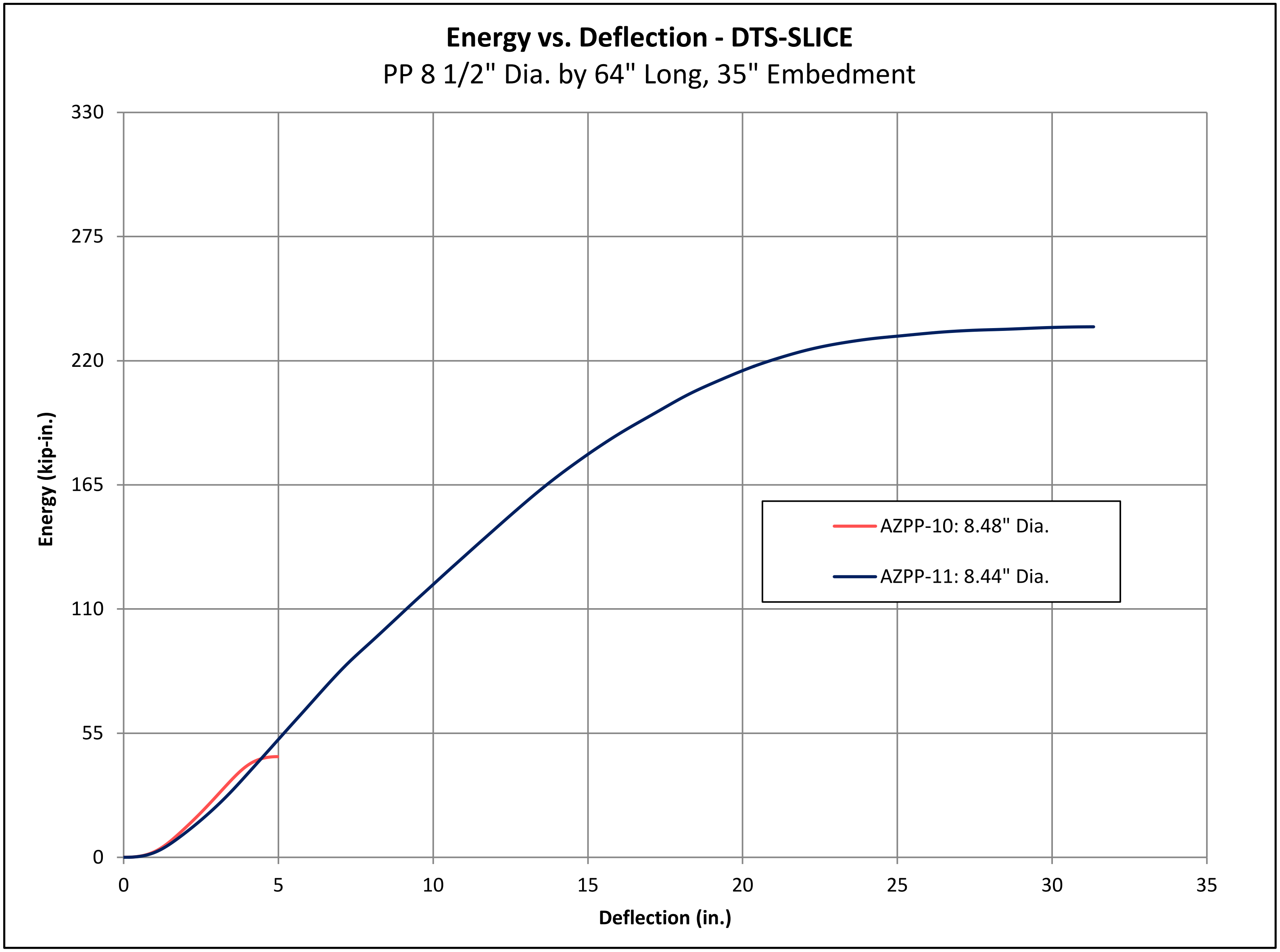

Figure 59. Energy vs. Deflection Comparison, Test Nos. AZPP-10 and AZPP-11

14 DISCUSSION OF TEST RESULTS – SYP AND PP POSTS

The results from the dynamic component tests on round PP posts were compared to those obtained from three tests (AZSYP-4 through AZSYP-6) on rectangular SYP posts. The 6-in. x 8-in. (152-mm x 203-mm) by 64-in. (1,626-mm) long SYP posts corresponded to the AzDOT G4(2W) standard guardrail. This testing and evaluation effort was conducted to determine an equivalent round PP post for use as a surrogate to the AzDOT's rectangular SYP post. As part of this study, several parameters were investigated for use in an equivalency analysis, including propensity for fracture, post-soil behavior, lateral resistive force, and energy dissipated.

A major factor that can contribute to premature post fracture is the presence of wood defects, such as knots, sloped grains, ring shakes, juvenile cores, or decaying cores. Wood posts have varied material behavior and are also prone to various defects. It is impractical to eliminate 100 percent of the wood defects in guardrail posts. Instead, grading is used to maintain wood defects within tolerable limits in order to reduce their negative impact on structural properties. When a post fractures prematurely after a few inches of deflection, it can no longer provide lateral resistance to an impacting vehicle, thus resulting is less energy absorbed. The safety performance of a guardrail system may be degraded by a lack of post resistance and decreased energy absorption, especially if too many posts fracture prematurely. Therefore, the recommended round PP post should demonstrate adequate strength and energy dissipation characteristics as well as provide no greater propensity to fracture than observed for rectangular SYP posts.

Three rectangular SYP posts were tested and evaluated using material that complied with the AzDOT standards. During the testing of the rectangular SYP posts, one of the three tests resulted in post fracture (test no. AZSYP-4). Thus, two of three rectangular posts rotated in soil (test nos. AZSYP-5 through AZSYP-6).

Eleven round PP posts were tested and evaluated. During this testing program, seven posts fractured. However, six out of the seven posts were found by FPL to have wood defects beyond the acceptable limits provided in the existing grading rules and should not be included in the evaluation (test nos. AZPP-1, AZPP-3, AZPP-4, AZPP-6, AZPP-7, and AZPP-9). One out of the seven fractured posts was properly graded (test no. AZPP-10). Four of eleven PP posts rotated in soil, and all four posts were properly graded (test nos. AZPP-2, AZPP-5, AZPP-8, and AZPP-11). Therefore, only five out of eleven round PP posts were properly graded, four of which rotated in soil. As such, the fracture rate for properly-graded, round PP posts (20%) was less than that observed for rectangular SYP posts (33%) when embedded in a highly-compacted soil material and subjected to impact testing.

A comparison of test results was performed for all posts that rotated in soil versus fractured, as summarized in Table 11. A comparison of force versus deflection and energy versus deflection for all posts that rotated in soil are shown in Figures 60 and 61, respectively. For the two SYP posts, the average peak force was 12.1 kips (53.8 kN), while the average force and average energy dissipation through 15 in. (381 mm) of deflection was 8.9 kips (39.6 kN) and 134.1 kip-in. (15.2 kJ), respectively. For the smaller two posts, the average calculated post diameter at ground line and at 8 in. (203 mm) below grade was 8.50 in. (216 mm) and 8.44 (214 mm), respectively. Using these smaller two PP posts, the average peak force was determined to be 14.8 kips (65.8 kN), while the average force and average energy dissipation through 15 in. (381 mm) of deflection was 12.1 kips (53.8 kN) and 180.1 kip-in. (20.3 kJ), respectively. Actually, the peak force, average force at 15 in. (381 mm), and energy dissipated at 15 in. (381 mm) were 22, 36, and 34 percent greater than observed for the rectangular SYP posts used in the AzDOT standard guardrail system, respectively. The post-soil resistance and energy dissipation characteristics for an 8½-in. (216-mm) diameter PP post indicate that it would be an acceptable surrogate post for use in the AzDOT G4(2W) system.

When test no. AZPP-2 was compared to test nos. AZPP-5 and AZPP-11, a slightly larger calculated diameter was found at ground line and at 8 in. (203 mm) below grade - 8.67 in. (220 mm) and 8.62 (219 mm), respectively. However, the peak force as well as average force and energy dissipation through 15 in. (381 mm) of deflection were very similar, albeit slightly lower than observed for the two PP posts with a targeted diameter of 8½ in. (216 mm). The post-soil resistance and energy dissipation characteristics for an 8⅝-in. (219-mm) diameter PP post would also be an acceptable surrogate post for use in the AzDOT G4(2W) system.

For test no. AZPP-8 and using a targeted diameter of 8¾ in. (222 mm), the calculated diameter at ground line and at 8 in. (203 mm) below grade was 8.71 in. (221 mm) and 8.83 (224 mm), respectively. However, the peak force as well as average force and energy dissipation through 15 in. (381 mm) of deflection were much higher than observed for the rectangular SYP posts as well as for the smaller three PP posts. Actually, the peak force, average force at 15 in. (381 mm), and energy dissipated at 15 in. (381 mm) were 69, 81, and 80 percent greater than observed for the rectangular SYP posts used in the AzDOT standard guardrail system, respectively. The post-soil resistance and energy dissipation characteristics for an 8¾-in. (222-mm) diameter PP post would provide an overdesigned surrogate post for use in the AzDOT G4(2W) system.

Table 11. Test Results for SYP and PP Posts with Rotation in Soil

Test No.	Target Diameter in. (mm)	Calculated Post Dia. at Groundline in. (mm)	Calculated Post Dia. 8" below Groundline in. (mm)	Embedment Depth in. (mm)	Ring Density (rings per in.)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Average Force kips (kN)			Maximum Deflection in. (mm)	Absorbed Energy kip-in. (kJ)		
								@ 10"	@ 15"	@ 20"		@ 10"	@ 15"	@ 20"
AZ Standard: 6"x8" Southern Yellow Pine Posts														
AZSYP-5	NA	NA	NA	35 (889)	9	19.8 (31.9)	11.1 (49.4)	8.5 (37.8)	7.9 (35.1)	6.9 (30.7)	31.3 (795)	84.9 (9.6)	119.5 (13.5)	140.4 (15.9)
AZSYP-6	NA	NA	NA	35 (889)	6.7	21.4 (34.4)	13.0 (57.8)	10.6 (47.2)	9.9 (44.0)	8.2 (36.5)	32.2 (818)	105.6 (11.9)	148.7 (16.8)	169.8 (19.2)
AVERAGE					**7.9**	**20.6 (33.2)**	**12.1 (53.8)**	**9.6 (42.7)**	**8.9 (39.6)**	**7.6 (33.8)**	**31.8 (806)**	**95.3 (10.8)**	**134.1 (15.2)**	**155.1 (17.5)**
Round Ponderosa Pine Posts, 8¼-in. (210 mm) Target Diameter														
AZPP-2	8¼ (210)	8.67 (220)	8.62 (219)	37 (940)	11.7	21.3 (34.3)	14.3 (63.6)	11.5 (51.2)	11.3 (50.3)	10.2 (45.4)	34.5 (876)	114.5 (12.9)	169.0 (19.1)	207.5 (23.4)
Round Ponderosa Pine Posts, 8½-in. (216 mm) Target Diameter														
AZPP-5	8½ (216)	8.55 (217)	8.53 (217)	35 (889)	11.7	20.2 (32.6)	14.2 (63.2)	11.8 (52.5)	12.2 (54.3)	11.2 (49.8)	32.3 (820)	117.3 (13.3)	181.4 (20.5)	228.0 (25.8)
AZPP-11	8½ (216)	8.44 (214)	8.36 (212)	35 (889)	12.7	21.9 (35.2)	15.4 (68.5)	12.2 (54.3)	11.9 (52.9)	10.6 (47.2)	31.3 (795)	121.1 (13.7)	178.7 (20.2)	215.7 (24.4)
AVERAGE					**12.2**	**21.1 (30.9)**	**14.8 (65.8)**	**12.0 (53.4)**	**12.1 (53.8)**	**10.9 (48.5)**	**31.8 (808)**	**119.2 (13.5)**	**180.1 (20.3)**	**221.9 (25.1)**
Round Ponderosa Pine Posts, 8¾-in. (222 mm) Target Diameter														
AZPP-8	8¾ (222)	8.71 (221)	8.83 (224)	35 (889)	13.7	21.1 (34.0)	20.5 (91.2)	16.6 (73.8)	16.1 (71.6)	13.7 (60.9)	28.9 (734)	163.5 (18.5)	241.2 (27.3)	289.8 (32.7)

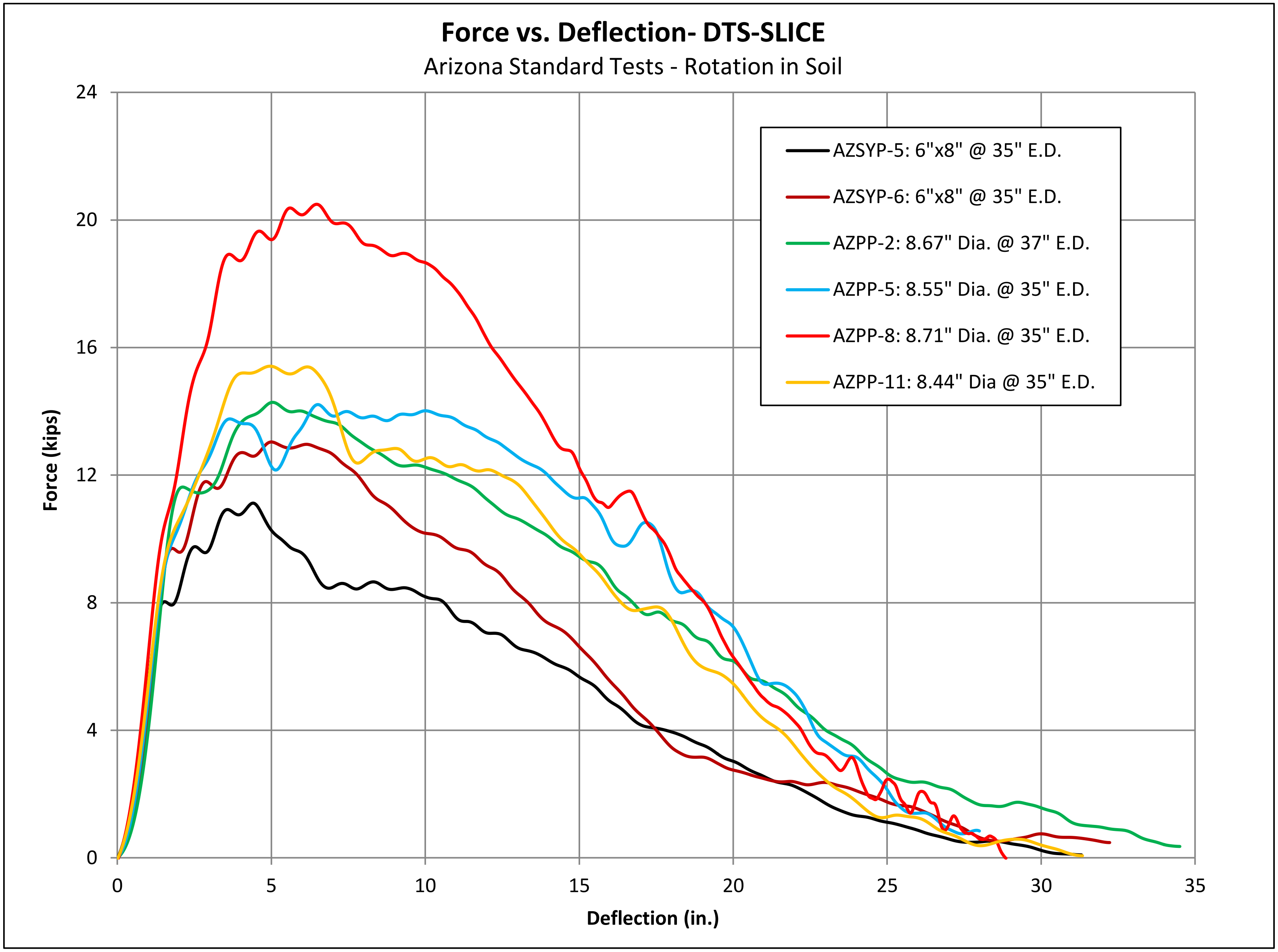

Figure 60. Force vs. Deflection Comparison, Tests with Post Rotation in Soil

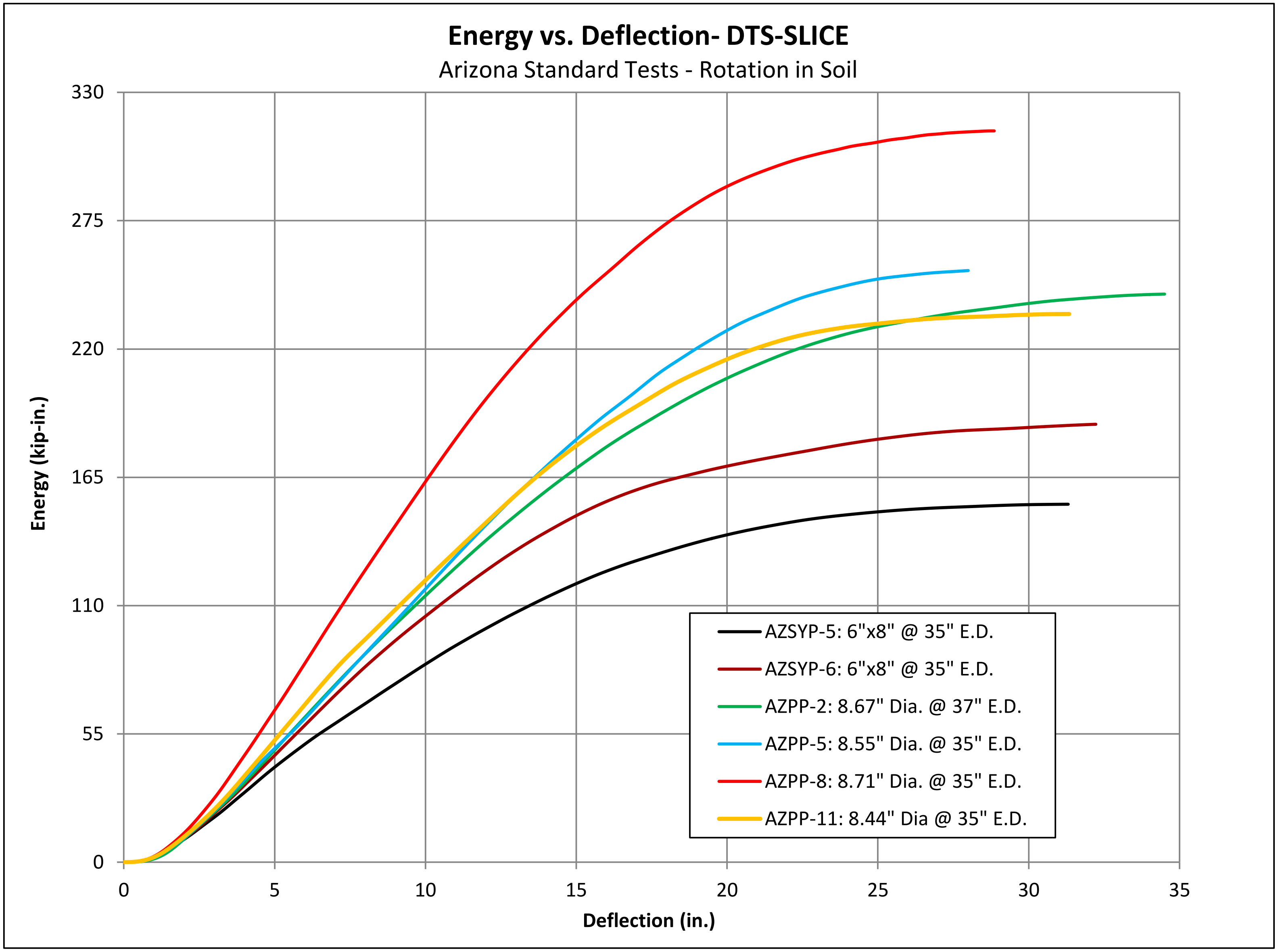

Figure 61. Energy vs. Deflection Comparison, Tests with Post Rotation in Soil

15 WEAK-AXIS CONSIDERATIONS

The bogie testing program reported herein was performed on wood posts embedded in a compacted, strong soil condition using an impact orientation which provides loading perpendicular to the longitudinal rail axis. As such, the rectangular posts were loaded about their strong-axis of bending. A PP post diameter, length, and embedment depth was determined to provide very similar post-soil behavior to that provided by 6-in. x 8-in. (152-mm x 203-mm) by 64-in. (1,626-mm) long SYP posts used in AzDOT standard W-beam guardrail systems, more specifically the G4(2W) system. The AzDOT also allows an alternative 8-in. x 8-in. (203-mm x 203-mm) wood post within G4(1W) W-beam guardrail systems, as shown in Appendix B.

Since only strong-axis bending was investigated in this study, it may be appropriate to discuss whether the weak-axis, post-soil strength of 6-in. x 8-in. (152-mm x 203-mm) rectangular SYP posts may influence guardrail performance. When a W-beam rail is laterally loaded, tensile forces and bending moments are largely imparted into the longitudinal beam. As such, the rail is often pulled inward toward the impact region and away from the end anchorages. At each interior post location, the axial rail load is transmitted to nearby blockouts, posts, and soil through guardrail bolt and nut connections. During full-scale crash tests, the safety performance of W-beam guardrail systems has not been significantly affected by weak-axis post capacity for line posts fabricated with common wood sizes. Occasionally, some side splitting has been observed near the top of wood posts at the bolt location although inconsequential.

The initial soil stiffness and longitudinal resistance of a 6-in. x 8-in. (152-mm x 203-mm) wood post in the direction perpendicular to the wide face [8-in. (203-mm) surface] would be greater than observed for the narrower face. However, the actual bending capacity of a 6-in. x 8-in. (152-mm x 203-mm) wood post is less under weak-axis bending as compared to strong-axis bending due to a reduced section modulus. For a wider surface area, increased soil stiffness, higher soil forces, and a comparable load height, the 6-in. x 8-in. (152-mm x 203-mm) wood post would likely fracture more quickly when loaded parallel to the rail.

For 6-in. x 8-in. (152-mm x 203-mm) wood posts embedded in soil, slightly different post-soil behavior may be observed between the parallel and perpendicular load directions. However, these differences have not been known to cause significant problems in existing W-beam guardrail designs. Further, wood posts with similar behavior in both directions have also demonstrated acceptable safety performance in W-beam guardrail systems and been approved for use. For example, both round and square SYP posts have performed in acceptable manner in W-beam guardrail and approach guardrail transitions [5, 18]. In addition, round SYP, PP, and DF posts have been successfully tested and evaluated for use within the 31-in. (787-mm) tall Midwest Guardrail System (MGS) under the NCHRP Report No. 350 impact safety standards [6]. Further, the American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* [18] has denoted 8-in. x 8-in. (203-mm x 203-mm) square posts as an acceptable alternative to 6-in. x 8-in. (152-mm x 203-mm) rectangular posts for both 72 in. (1,829 mm) and 64 in. (1,626 mm) lengths for standard guardrail designs. As such, round PP posts should behave similarly to the previously-accepted round SYP, PP, and DF posts and square wood posts used in standard W-beam guardrail systems when considering post loading parallel to the longitudinal rail axis.

16 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The primary objective of this research study was to determine the appropriate size and embedment depth for round PP posts in order to serve as a surrogate for standard 6-in. x 8-in. (152-mm x 203-mm) by 64-in. (1,626-mm) long SYP posts used in AzDOT standard W-beam guardrail systems, more specifically the G4(2W) system. This component testing program was conducted to determine an alternative round wood post for use in existing guardrail systems that have met or been grandfathered under the impact safety standards published in the National Cooperative Highway Research Program (NCHRP) Report No. 350.

To complete the objective noted above, the study examined the post-soil behavior of PP round posts and SYP rectangular posts subjected to impact loading. Propensity for fracture, post-soil behavior, lateral resistive force, and energy absorption characteristics were evaluated for all embedded posts. Another objective was to determine the appropriate size and embedment depth for round PP posts that could be substituted for SYP posts used in U.S. standard guardrail systems, those which utilize 6-in. x 8-in. (152-mm x 203-mm) by 72-in. (1,829-mm) long SYP posts. This second objective will be addressed in a follow-on study.

Seventeen dynamic component tests were conducted – six with 6-in. x 8-in. (152-mm x 203-mm) SYP posts (three corresponding to each of the AzDOT and U.S. standard configurations) and eleven with various sizes of round PP posts. All seventeen tests were conducted with an impact height of 21.65 in. (550 mm) and a target impact speed of 20 mph (32.2 km/h). The results of these bogie tests are summarized in Table 12.

For the AzDOT standard SYP posts, two of three rectangular posts rotated in soil versus fractured prematurely. After identifying wood grading issues with the round PP posts and as discussed in Chapter 12, it was observed that five out of eleven round PP posts were properly graded, four of which rotated in soil. Thus, the fracture rate for properly-graded, round PP posts (20%) was less than that observed for rectangular SYP posts (33%) when embedded in a highly-compacted soil material and subjected to impact testing, as noted in Chapter 14.

Several tests were conducted on PP posts with various targeted ground line diameters. For PP posts with a target ground line diameter of 8½ in. (216 mm), the peak force, average force at 15 in. (381 mm), and energy dissipated at 15 in. (381 mm) were 22, 36, and 34 percent greater than observed for the rectangular SYP posts used in the AzDOT standard guardrail system, respectively. The post-soil resistance and energy dissipation characteristics for an 8½-in. (216-mm) diameter PP post with a 35-in. (889-mm) embedment depth were found acceptable, thus allowing the PP post to serve as a surrogate in the AzDOT G4(2W) system.

For PP posts with a target ground line diameter of 8⅝-in. (219-mm), the peak force as well as average force and energy dissipation through 15 in. (381 mm) of deflection were very similar, albeit slightly lower than observed for the two PP posts with a targeted diameter of 8½ in. (216 mm). Thus, the post-soil resistance and energy dissipation characteristics for an 8⅝-in. (219-mm) diameter PP post with a 35-in. (889-mm) embedment depth would also be an acceptable surrogate post for use in the AzDOT G4(2W) system.

When considering the PP posts with a target ground line diameter of 8¾ in. (222 mm), the peak force, average force at 15 in. (381 mm), and energy dissipated at 15 in. (381 mm) were 69, 81, and 80 percent greater than observed for the rectangular SYP posts used in the AzDOT standard guardrail system, respectively. The post-soil resistance and energy dissipation characteristics for an 8¾-in. (222-mm) diameter PP post with a 35-in. (889-mm) embedment depth would provide an overdesigned surrogate post for use in the AzDOT G4(2W) system.

Based on the test results obtained from the three targeted PP post diameters as well as from the SYP posts, an 8½ in. (216 mm) minimum ground line diameter was recommended for a surrogate PP post. The 8½-in. (216-mm) diameter x 64-in. (1,626-mm) long PP post with an embedment depth of 35 in. (889 mm) provided a closer match to the post-soil performance of 6-in. x 8-in. (152-mm x 203-mm) x 64-in. (1,626-mm) long SYP posts currently used in AzDOT G4(2W) guardrail systems as compared to the other post sizes that were evaluated. Thus, the recommended minimum ground line diameter for a PP post used in AzDOT G4(2W) guardrail systems is 8½ in. (216 mm). At this time, the research team believes that a fabrication tolerance of minus 0 in. to plus ½ in., or 8½ in. to 9 in., would provide a reasonable range for the ground line diameter. However, further refinement of this range may be considered in the future.

Design details and material specifications have been prepared to support the implementation of the surrogate Ponderosa Pine round posts into G4(2W) guardrail systems used by the Arizona DOT, as provided in Appendix E. Special attention should be directed toward the proper inspection of timber materials and emphasis for timber suppliers to follow the proposed PP round-post dimensions and grading criteria provided in Appendix E. These measures should help to ensure that the PP posts are fabricated from suitable wood, have adequate strength, provide similar post-soil behavior to the rectangular SYP posts studied herein, and allow for the G4(2W) guardrail system to perform in an acceptable manner when using either round PP posts or rectangular SYP posts.

Table 12. Summary of Dynamic Bogie Testing Results

Test No.	Post Size in. (mm)	Timber Species	Embedment Depth in. (mm)	Failure Mechanism	Peak Force kips (kN)	Average Force kips (kN)		Maximum Deflection in. (mm)
						@ 15"	@ 20"	
AZSYP-1	6x8 (152x203)	SYP	43¼ (1,009)	Post Fracture	18.5 (82.3)	6.4* (28.5)	NA	18.6 (472)
AZSYP-2	6x8 (152x203)	SYP	43¼ (1,009)	Post Fracture	13.5 (60.0)	5.8* (25.8)	NA	17.6 (447)
AZSYP-3	6x8 (152x203)	SYP	43¼ (1,009)	Rotation in Soil	16.4 (73.0)	12.7 (56.5)	10.8 (48.0)	63.7 (1,618)
AZSYP-4	6x8 (152x203)	SYP	35 (889)	Post Fracture	7.2 (32.2)	NA	NA	4.0 (102)
AZSYP-5	6x8 (152x203)	SYP	35 (889)	Rotation in Soil	11.1 (49.4)	7.9 (35.1)	6.9 (30.7)	31.3 (795)
AZSYP-6	6x8 (152x203)	SYP	35 (889)	Rotation in Soil	13.0 (57.8)	9.9 (44.0)	8.2 (36.5)	32.2 (818)
AZPP-1	8.48 (215)	PP	37 (940)	Post Fracture	14.7 (65.4)	5.0* (22.2)	NA	17.3 (439)
AZPP-2	8.67 (220)	PP	37 (940)	Rotation in Soil	14.3 (63.6)	11.3 (50.3)	10.2 (45.4)	34.5 (876)
AZPP-3	8.48 (215)	PP	37 (940)	Post Fracture	11.7 (52.0)	NA	NA	6.2 (157)
AZPP-4	8.55 (216)	PP	35 (889)	Post Fracture	17.0 (75.6)	NA	NA	5.7 (145)
AZPP-5	8.55 (217)	PP	35 (889)	Rotation in Soil	14.2 (63.2)	12.2 (54.3)	11.2 (49.8)	32.3 (820)
AZPP-6	8.36 (212)	PP	35 (889)	Post Fracture	12.4 (55.2)	NA	NA	4.9 (124)
AZPP-7	8.67 (220)	PP	35 (889)	Post Fracture	16.5 (73.4)	NA	NA	6.4 (163)
AZPP-8	8.71 (221)	PP	35 (889)	Rotation in Soil	20.5 (91.2)	16.1 (71.6)	13.7 (60.9)	28.8 (732)
AZPP-9	8.75 (222)	PP	35 (889)	Post Fracture	9.2 (40.9)	NA	NA	4.9 (124)
AZPP-10	8.48 (215)	PP	35 (889)	Post Fracture	15.0 (66.7)	NA	NA	5.0 (127)
AZPP-11	8.44 (214)	PP	35 (889)	Rotation in Soil	15.4 (68.5)	11.9 (52.9)	10.6 (47.2)	31.3 (795)

*Post fracture had begun prior to reaching the deflection listed.

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18 APPENDICES

Appendix A. FPL Bogie Test Results

Test results are provided for the FPL bogie tests from a previous study conducted by Hascall, et al. [5].

Table A-1. FPL Dynamic Test Results Overview [5]

	Post Test No.	Test Date	Species	In Soil Diameter mm	In Soil Diameter (in.)	Embedment Depth mm	Embedment Depth (in.)	Moisture Content (%)	Impact Velocity m/s	Impact Velocity (mph)	Final Post Status
Ponderosa Pine	PP-31	9/16/2005	PP	183.76	(7.24)	1016	(40.00)	29	11.7	(26.2)	Fractured
Ponderosa Pine	PP-32	9/19/2005	PP	184.77	(7.28)	1016	(40.00)	48	10.9	(24.5)	Fractured
Ponderosa Pine	PP-33	9/29/2005	SYP	185.93	(7.32)	940	(37.00)	10	11.5	(25.7)	Fractured
Ponderosa Pine			**Avg.**	**184.82**	**(7.28)**			**29**	**11.4**	**(25.5)**	
Ponderosa Pine			**St. Dev.**	**1.09**	**(0.04)**			**19**	**0.4**	**(0.9)**	
Ponderosa Pine	PP-34	11/7/2005	PP	202.44	(7.97)	940	(37.00)	25	10.9	(24.3)	Rotated
Ponderosa Pine	PP-35	11/7/2005	PP	200.66	(7.90)	940	(37.00)	24	11.3	(25.3)	Rotated
Ponderosa Pine	PP-36	11/7/2005	PP	199.14	(7.84)	940	(37.00)	20	10.6	(23.8)	Rotated
Ponderosa Pine	PP-37	11/7/2005	PP	194.06	(7.64)	940	(37.00)	23	11.2	(25.1)	Rotated
Ponderosa Pine			**Avg.**	**199.07**	**(7.84)**			**23**	**11.0**	**(24.6)**	
Ponderosa Pine			**St. Dev.**	**3.61**	**(0.14)**			**2**	**0.3**	**(0.7)**	
Douglas Fir	DF-31	9/19/2005	SYP	165.48	(6.52)	1016	(40.00)	17	11.1	(24.8)	Rotated
Douglas Fir	DF-32	9/19/2005	PP	165.48	(6.52)	1016	(40.00)	15	10.9	(24.4)	Fractured
Douglas Fir	DF-33	9/23/2005	SYP	168.28	(6.63)	940	(37.00)	17	10.8	(24.2)	Fractured
Douglas Fir			**Avg.**	**166.41**	**(6.56)**			**16**	**10.9**	**(24.4)**	
Douglas Fir			**St. Dev.**	**1.61**	**(0.06)**			**1**	**0.1**	**(0.3)**	
Douglas Fir	DF-34	10/4/2005	DF	181.86	(7.16)	940	(37.00)	15	11.2	(25.1)	Rotated
Douglas Fir	DF-35	10/5/2005	DF	180.34	(7.10)	940	(37.00)	19	11.5	(25.7)	Rotated
Douglas Fir	DF-36	10/5/2005	DF	175.26	(6.90)	940	(37.00)	18	11.1	(24.8)	Fractured
Douglas Fir			**Avg.**	**179.15**	**(7.05)**			**17**	**11.3**	**(25.2)**	
Douglas Fir			**St. Dev.**	**3.46**	**(0.14)**			**2**	**0.2**	**(0.4)**	
Southern Yellow Pine	SY-31	12/16/2005	SYP	186.44	(7.34)	940	(37.00)	21	10.9	(24.3)	Fractured
Southern Yellow Pine	SY-32	12/16/2005	SYP	185.17	(7.29)	940	(37.00)	30	11.4	(25.4)	Rotated
Southern Yellow Pine	SY-33	12/16/2005	SYP	183.90	(7.24)	940	(37.00)	25	11.6	(26.0)	Rotated
Southern Yellow Pine			**Avg.**	**185.17**	**(7.29)**			**25**	**11.3**	**(25.3)**	
Southern Yellow Pine			**St. Dev.**	**1.27**	**(0.05)**			**5**	**0.4**	**(0.9)**	
Southern Yellow Pine	RWP-1	9/29/2005	SYP	152 x 203	(6 x 8)	940	(37.00)	NA	11.6	(25.9)	Rotated
Southern Yellow Pine	RWP-2	9/29/2005	SYP	152 x 203	(6 x 8)	1016	(40.00)	NA	11.2	(25.2)	Rotated
Southern Yellow Pine			**Avg.**	**152 x 203**	**(6 x 8)**		**(38.50)**	**NA**	**7.7**	**(17.3)**	
Southern Yellow Pine			**St. Dev.**				**(2.12)**	**NA**	**6.4**	**(14.3)**	

Table A-2. FPL Dynamic Test Results Summary [5]

	Post Test No.	Peak Force							381 mm (15 in.) Deflection			Final				
		Time	Force		Deflection		Energy		Time	Energy		Time	Deflection		Energy	
		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)**
Southern Yellow Pine	SY-31	5.3	53.6	(12.1)	57	(2.3)	1.48	(13.1)	36.6	6.32	(55.9)	91.2	898	(35.3)	13.95	(123.4)
	SY-32	5.6	68.2	(15.3)	64	(2.5)	1.94	(17.2)	35.0	6.86	(60.7)	143.3	1417	(55.8)	18.84	(166.8)
	SY-33	5.6	69.4	(15.6)	65	(2.6)	1.99	(17.6)	34.4	7.86	(69.6)	139.1	1338	(52.7)	24.80	(219.5)
	Avg.	**5.5**	**63.7**	**(14.3)**	**62**	**(2.4)**	**1.80**	**(16.0)**	**35.3**	**7.01**	**(62.1)**	**124.5**	**1218**	**(47.9)**	**19.20**	**(169.9)**
	St. Dev.	**0.2**	**8.8**	**(2.0)**	**4**	**(0.2)**	**0.28**	**(2.5)**	**1.1**	**0.78**	**(6.9)**	**28.9**	**280**	**(11.0)**	**5.44**	**(48.1)**
	RWP-1	5.3	69.7	(15.7)	61	(2.4)	2.03	(17.9)	35.6	13.86	(122.7)	119.7	1076	(42.4)	27.95	(247.3)
	RWP-2	40.3	62.7	(14.1)	405	(15.9)	19.57	(173.2)	37.5	18.07	(160.0)	145.9	975	(38.4)	40.57	(359.0)
	Avg.	**15.3**	**66.2**	**(14.9)**	**157**	**(6.2)**	**7.29**	**(95.6)**	**36.6**	**15.97**	**(141.3)**	**98.2**	**777**	**(30.6)**	**24.65**	**(218.2)**
	St. Dev.	**21.8**	**5.0**	**(1.1)**	**217**	**(8.5)**	**10.67**	**(94.4)**	**1.3**	**2.98**	**(26.3)**	**61.4**	**433**	**(17.1)**	**17.80**	**(157.5)**

Table A-3. FPL Dynamic Ponderosa Pine Round Post Test Results [5]

	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	(kips/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		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		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		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		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		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		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		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		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		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		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		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		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**

Limited by Maximum Deflection Criterion (20 in.)

Limited by Time of Contact

Appendix B. AzDOT Standard Plans & Specifications and Other Material Certifications

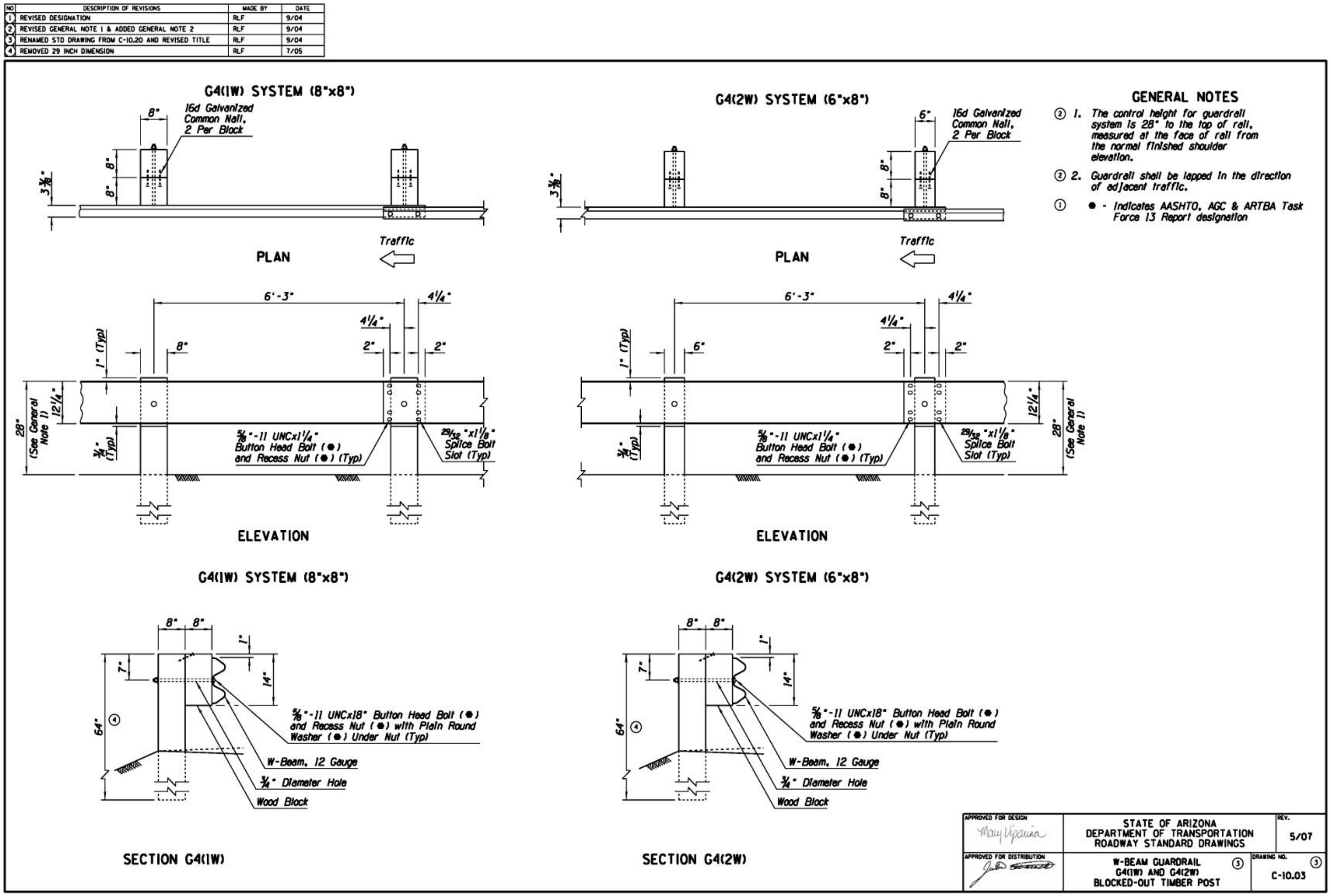


Figure A-1. AzDOT Guardrail Specifications with Blocked-Out Timber Post

ARIZONA DEPARTMENT OF TRANSPORTATION * MATERIALS GROUP

1221 NORTH 21ST AVENUE PHOENIX, ARIZONA 85009-3740 PHONE (602) 712 - 7231

POLICY AND PROCEDURE DIRECTIVE

James P. Delton
Assistant State Engineer

TO: ALL MANUAL HOLDERS	PPD NO. 9
SUBJECT: GUIDELINES FOR INSPECTION AND ACCEPTANCE OF TIMBER GUARDRAIL POSTS AND BLOCKS	EFFECTIVE DATE: February 27, 2009

1. GENERAL

1.1 This Policy and Procedure Directive supersedes P.P.D. No. 02-01.

1.2 The purpose of this directive is to provide guidelines in the inspection and acceptance of timber guardrail posts and blocks, which ensure a product with proper preservation treatment, adequate strength, and good appearance.

1.3 Solid timber posts and blocks may be either rough sawn (unsurfaced) or S4S (surfaced four sides) lumber.

1.4 Glued laminated timber shall be constructed according to the requirements of ANSI/AITC (American National Standards Institute/American Institute of Timber Construction). The manufacturing plant for glued laminated timber shall be certified and licensed by AITC. The manufacturer of glue laminated timber posts shall brand the tension face of the post in an area which will be above the ground line and below the bottom of the block. Laminated posts shall be installed with the tension face of the post facing the roadway.

2. APPLICABLE DOCUMENTS

2.1 ADOT Standard Specifications, Section 1012
2.2 American Wood Preservers Association (AWPA)
2.3 Western Wood Products Association (WWPA)
2.4 AASHTO M 133, and M 168
2.5 ASTM D 2559
2.6 American National Standards Institute (ANSI)
2.7 American Institute of Timber Construction (AITC) 113
2.8 ANSI/AITC A 190.1
2.9 International Conference of Building Officials, Evaluation Service (ICBO ES)

3. CLASSIFICATION

3.1 Solid Timber Posts and Blocks:

3.1.1 Solid timber, rough sawn shall be graded in accordance with WWPA Grading Rules, Section 80.00 for Post and Timbers, No. 1 or better.

3.1.2 Solid timber, S4S shall be graded in accordance with WWPA Grading Rules, Section 80.00 for Post and Timbers, No. 1 or better.

3.2 Glue Laminated Timber Posts and Blocks:

3.2.1 Lumber used for glue laminated timber guard rail posts and blocks shall conform to WWPA Grading Rules, Section 62.00, Structural Joists and Planks, No. 1 or better S4S lumber.

3.2.2 Adhesive used to bond laminated wood products shall be a two-component system that complies with ASTM D 2559 and has passed the ICBO ES, Acceptance Criteria for Exterior Sandwich Panel Adhesives (AC05).

3.2.3 Laminated posts and blocks shall be glued together in a face-to-face glue joining, conforming to the requirements of AITC standards.

3.3 The required posts and blocks sizes shown in the contract documents shall be understood to be nominal dimensions. Allowable tolerances are shown in Subsection 5.5, Field Inspection.

4. WOOD PRESERVATION TREATMENT & FABRICATION

4.1 Drilling or fabrication should be done where possible before preservation treatment process. In event of a mechanical injury or field cutting, field treatment should be in accordance with AWPA Standard M2.

4.2 The treatment process, including seasoning shall be in accordance with the requirements of AASHTO M 133, and AWPA C1, C2, and C28.

4.3 The inspection at the wood preservation plant for posts and blocks shall conform to the requirements of AWPA M2.

4.4 The Materials Central Laboratory or the Regional Materials Laboratory nearest to the treatment plant may conduct the inspections at wood preservation plants or fabrication facilities within the state. For wood preservation plants or fabrication facilities outside the state, an approved consulting inspection service may be engaged.

4.5 A quality check on the certification procedure for the treatment of posts and blocks, a spot check type of inspection of the wood preservation plant facilities, will be periodically performed. This will include observing the conditioning process, checking the residual moisture before treatment, checking sampling and testing preservative agents, and checking assay procedures.

5. FIELD INSPECTION

5.1 The responsibility for acceptance of the posts and blocks will be that of the Engineer on the Project. Certification by the wood preservation plant will not substitute for the inspection for "Grade of Lumber".

5.2 A copy of the certification for preservation treatment and stress grade, together with the treatment assay sheet is to accompany each shipment of posts and blocks.

5.3 The contractor shall submit to the Engineer a Certificate of Compliance conforming to the requirements of the ADOT Standard Specifications Subsection 106.05. The certificate shall be furnished by the post and block supplier and shall also include the following information: (a) Identification of the qualified inspection and testing agency, (b) the species or species group of lumber as well as the grade, and (c) identification of the recognized standard to be used as an acceptance basis for this product.

5.4 Unloading, handling, and job site storage procedures:

5.4.1 Cable slings or chokers should not be used to handle post and block materials unless adequate blocking is provided between the cable and the wood member. Protection cleats or blocking shall applied at pick-up points to protect corners. A level storage area is required to avoid warping. Wood members shall be supported with blocking so spaced as to provide uniform and adequate support. Stored wood members shall have the top and all of the sides covered with a moisture resistant covering.

5.5 Allowable dimensional tolerances for posts and blocks:

5.5.1 Dimensional tolerances for solid timber rough sawn posts and blocks shall be plus or minus 1/16 inch in thickness and width; and plus or minus 1/8 inch in length.

5.5.2 Dimensional tolerances for solid timber (S4S) posts and blocks shall be plus or minus 1/2 inch in thickness and width; and plus or minus 1/8 inch in length.

5.5.3 The standard dimensions for glue laminated posts and blocks (S4S) with a nominal dimension of 6 inches x 8 inches shall be finished to the dimensions of 5-1/2 inches x 7-1/2 inches, according to AITC 113. Dimensional tolerances for glue laminated lumber posts and blocks shall be plus or minus 1/16 inch in thickness and width; and plus or minus 1/8 inch in length.

5.6 The following are guidelines for inspection of appearance and physical characteristics for grade. Definitions, characteristics, and the maximum allowable values are listed below for solid timber and glue laminated posts and blocks. See WWPA Section 80.00 for additional information for solid timber posts and blocks. See WWPA Section 62.00 for additional information for lumber used in glue laminated posts and blocks.

5.6.1 **Grain** – *The fibers in wood and their direction, size, arrangement, or quality.* A medium grain is required, which means an average of 4 or more annual rings per inch measured on a line perpendicular to the rings. See Attachment #1 and WWPA Section 170.00 for additional information.

Slope of grain is the deviation of the wood fiber from a line parallel to the edges of the piece. A maximum deviation of 1 in 10 is allowable. See Attachment #2, WWPA Section 230.00, and WWPA Section 712.00 for additional information.

5.6.2 **Sapwood** – *The outer layers of growth between the bark and the heartwood which contain the sap.* For further explanation see WWPA Section 738.00.

5.6.3 **Heartwood** – *The inner core of the tree trunk comprising the annual rings containing nonliving elements.* In some species, heartwood has a prominent color different from the sapwood. For further explanation see WWPA Section 714.00.

5.6.4 **Splits** – *A separation of the wood through the piece to the opposite surface or to an adjoining surface due to the tearing apart of the wood cells.* A split which extends into the piece on a plane parallel to the bolthole shall not be accepted. See Attachment #1.

For solid timber guard rail posts and blocks, the length of a split shall not exceed the width of the piece. Splits equal in length to the width of the piece, or equivalent to the total length of end checks, are permissible. See Attachments #1 and #2.

For lumber used for glue laminated posts and blocks, splits equal in length to the width of the piece are permissible. For further explanation see WWPA Section 742.00.

5.6.5 **Checks** – *A separation of the wood normally occurring across or through the rings of annual growth and usually as a result of seasoning.* Checks are measured as the penetration perpendicular to the widest face. Where two or more checks appear on the same face, only the deepest one is measured. Where two checks are directly opposite each other, the sum of their depths are taken.

For solid timber posts and blocks, checks are allowed to be a maximum of 1/2 the thickness of the post or block for single checks, or for checks opposite each other the sum of their depths is allowed to be a maximum of 1/2 the thickness of the post or block. See Attachment #1.

Checks in glue laminated timber guard rail posts and blocks may appear as openings parallel to the grain on the sides of the members, (See Attachments #1, #2, and #3). Surface seasoning checks are not limited. Checks which are located outside the shear critical zone (See Attachment #4) and which run in the direction of the length of the post are permitted to be a maximum of 3/16 inch in width and have a depth of not greater than 1/3 of the width of the laminated member. Allowable checks in the shear critical zone are determined by the equations shown in Attachment #4 [("d"$_{allowable}$ = 0.1W) and ("l"$_{allowable}$ = 0.9W), but "l"$_{allowable}$ shall not be greater than 6 inches]. The length (l) of side checks is not restricted. Through checks at ends are limited as for splits, see Attachment #1.

5.6.5 **Holes** – *Holes may either extend partially or wholly through the piece. An alternate designation for holes, which extend only partially through the piece, is surface pits.* Limitations shown below do not include holes drilled for hardware.

For solid timber guard rail posts and blocks, holes shall be limited to pin hole sizes. A pinhole is defined as not being over 1/16 inch in diameter.

Holes in lumber for glue laminated posts and blocks from any cause shall be limited to a maximum of 1-1/4 inches, and are further limited to one hole of a maximum of 1-1/4 inches, or equivalent smaller holes, for each 3 linear feet. For further explanation see WWPA Section 716.00.

5.6.6 **Skips** – *Skips are areas on a piece that failed to surface clean.*

For solid timber guard rail posts and blocks, occasional skips up to 1/8 inch in depth and two feet in length are allowable.

Hit-and-miss skips in lumber for glue laminated guard rail posts and blocks are allowed in a maximum of 10% of the pieces. Hit-and-miss skips are defined as skips which are a series of skips not over 1/16 of an inch deep with surfaced areas between.

5.6.7 **Wane** – *Bark or lack of wood from any cause, except eased edges, on the edge or corner of a piece of lumber.*

For solid timber guard rail posts and blocks, wane which is 1/4, or equivalent, of any face is allowed.

For lumber used in glue laminated guard rail posts and blocks, the allowable wane is 1/4, or equivalent, of the full length of the thickness face and 1/4, or equivalent, of the full length of the width face, provided that wane does not exceed 1/2 the thickness or 1/3 the width for up to 1/4 the length. For further explanation see WWPA Section 750.00.

5.6.8 **Shake** – *A lengthwise separation of the wood, which occurs between or through the rings of annual growth.*

For solid timber guard rail posts and blocks, shake of up to 1/3 the thickness is allowed, see Attachment #1.

For lumber used in glue laminated guard rail posts and blocks, through shakes at ends are limited as for splits. Surface shakes up to two feet in length are allowed, see Attachments #1, #2, and #3. For further explanation see WWPA Section 740.00.

5.6.9 **Knots** – *A portion of a branch or limb that has become incorporated in a piece of lumber.* Knots, which are sound and tight, and well spaced, are permitted. A sound knot contains no decay. A tight knot is so fixed by growth, shape or position that it retains its place in the piece.

For solid timber guard rail posts and blocks, the knot size limitation on a nominal 6-inch face is 1-7/8 inches, while on an 8-inch face the knot size is limited to 2-1/2 inches. See Attachment #1.

For lumber used in glue laminated guard rail posts and blocks, knots at the edge of the wide face for a nominal width face of 6 inches are limited to1-1/2 inches. Knots at the centerline of the wide face for a nominal width face of 6 inches are limited to 2-1/4 inches.

SECTION 1001 MATERIAL SOURCES:

1012-4 Timber Guardrail, Posts and Blocks:

Timber for posts and blocks shall be rough sawn (unplaned) or S4S with the nominal dimensions indicated. Any species or group of woods graded in accordance with the requirements for Timber and Posts of the Western Wood Products Association may be used.

Timber shall be No. 1 or better, and the stress grade shall be as follows:

6 inch by 8 inch Post and Block	1,200 psi
8 inch by 8 inch Post and Block	900 psi
10 inch by 10 inch Post and Block	900 psi

When the plans show guardrail systems using eight-inch by eight-inch timber posts and blocks, the contractor may use 8-1/4 inch by 8-1/4 inch nominal size posts and blocks with a stress grade of 825 pounds per square inch.

At the time of installation, the dimensions of timber posts and blocks shall vary no more than ± 1/2 inch from the nominal dimensions as hereinbefore specified.

The size tolerance of rough sawn blocks in the direction of the bolt holes shall vary no more than ± 3/8 inch. Only one type of post and block shall be used for any one continuous length of guardrail.

All timber shall have a preservative treatment in accordance with the requirements of AASHTO M 133.

Arizona Log & TimberWorks

Phone 928-333-2751 Fax: 928-333-2758

June 21, 2012

This is to certify that the materials delivered to Midwest Roadside Safety Facility in Lincoln, Nebraska was manufactured to the specifications listed on the plans sheet 4 of 4 provide by the Midwest Roadside Safety Facility dated 06/01/2012. See the attached "shipping" invoice # 4418 for the list of post.

Randy Nicoll – Owner
Arizona Log & TimberWorks

1990 W. Central Ave., Eagar, AZ 85925

Figure B-1. General Certification for All Posts

Arizona Log & TimberWorks
1990 W. Central Ave
Eagar, AZ 85925
USA

Voice: 928-333-2751
Fax: 928-333-2758

SHIPPING

Invoice Number: 4418
Invoice Date: Jun 13, 2012
Page: 1

Sales Order Number:

Bill To:	Ship to:
Cash	Cash Midwest Roadside Safety Facili 4800 N.W. 35th St. Lincoln, NE 68524

Customer ID	Customer PO	Payment Terms	
Cash	Ron Faller	C.O.D.	
Sales Rep ID	**Shipping Method**	**Ship Date**	**Due Date**
	Our Truck		6/13/12

Order Qty	Item	Description	Shipped Prior	This Shipment	Corrections
10.00		8-1/4" X 66" Round Pon Pine Post		10.00	
10.00		8-1/4" X 76" Round Pon Pine Post		10.00	
10.00		7-3/4" X 76" Round Pon Pine Post		10.00	
10.00		8-3/4" X 76" Round Pon Pine Post		10.00	
10.00		9" X 76" Round Pon Pine Post		10.00	
10.00		9-1/2" X 76" Round Pon Pine Post		10.00	
10.00		10" X 76" Round Pon Pine Post		10.00	
6.00		7-1/2" X ~~76"~~ Round Pon Pine Post 70"		6.00	
12.00		6" X 8" X 6' SYP Post		12.00	

Figure B-2. General Certification for All Posts

06/21/2012 15:21 9286368945 AZ HWY SAFETY PAGE 01/01

TRIO FOREST PRODUCTS INC.

P.O BOX 1465
MESA, AZ 85211

CERTIFICATION OF SPECIFICATION OF COMPLIANCE
TIMBER GUARD POST, ANCHORS, AND BLOCKS
ARIZONA DEPARTMENT OF TRANSPORTATION

PURCHASER Arizona Highway Safety Specialists
PO#

PRIME CONTRACTOR:

PROJECT: **PROJECT#:**

DESCRIPTION:

12 PCS 6X8 X 6' POST
MATERIAL IS #1 SYP

Certification: (1) This is to certify that the Timber Guard Post and Blocks listed herein, conform to the Arizona Department of Transportation requirements of Section 1012.

(2) Posts furnished are Pressured Treated with Chromated Copper Arsenate. Assay and penetrations tests have been performed and the material meets AWPA C-2 requirements.

Jerry Lilly
JERRY LILLY VICE PRESIDENT
TRIO FOREST PRODUCTS INC

Figure B-3. Post Material Certification for Test Nos. AZSYP-1 through AZSYP-6

Round Ponderosa Pine Post Grading Criteria

General:

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 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 35 in. (889 mm) or 37 in. (940 mm) 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. The ground-line diameter shall be specified by diameter in ¼ in. (6 mm) breaks. The length shall be specified in 12 in. (305 mm) 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 3 in. (76 mm) 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. (25 mm).

Shape and Straightness:

All PP 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 1¼ in. (32 mm) 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 exceeding 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.

Knots:

Knot diameter for Ponderosa Pine posts shall be limited to 3.5 in. (89 mm) or smaller.

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 treated post shall have a minimum sapwood depth of $^3/_4$ in. (19 mm), 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.

Decay:

Allowed in knots only.

Holes:

Pin holes $^{1}/_{16}$ in. (1 mm) or less are not restricted.

Slope of Grain:

1 in 10.

Compression Wood:

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

Ring Density:

Ring density shall be at least 6 rings-per-inch, as measured over a 3 in. (76 mm) distance

Appendix C. Bogie Test Results

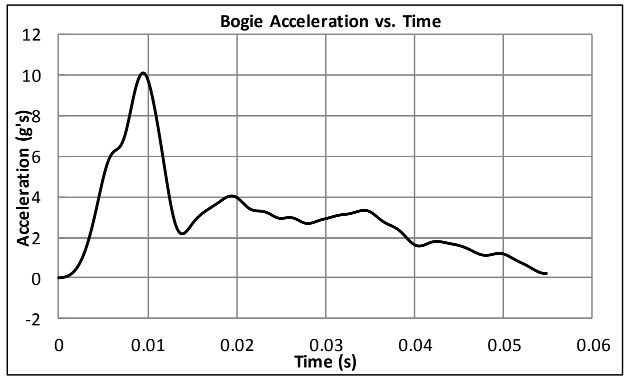
Test results were determined from the recorded data for each accelerometer in each dynamic bogie test and shown in this appendix. Summary sheets include acceleration, velocity, and deflection vs. time plots as well as force vs. deflection and energy vs. deflection plots.

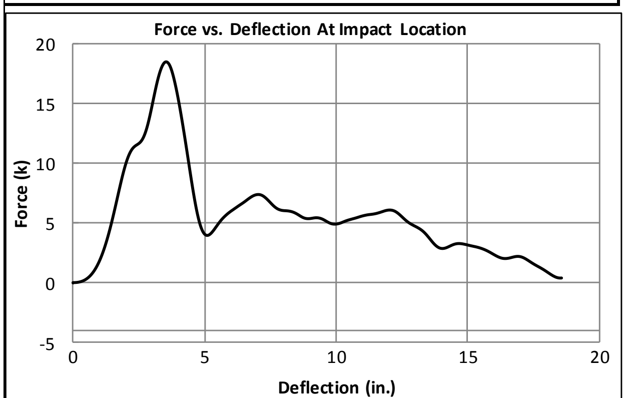
MIDWEST ROADSIDE SAFETY FACILITY

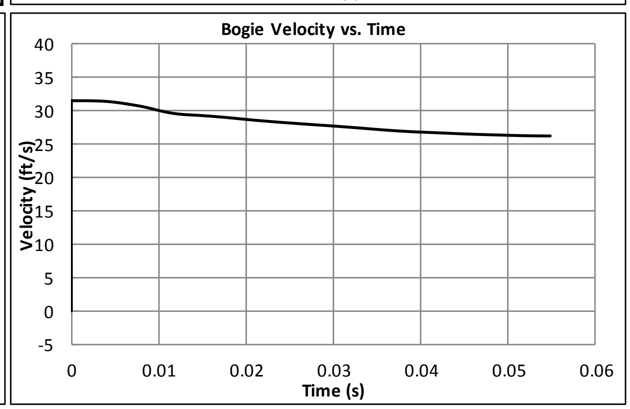
Bogie Test Summary

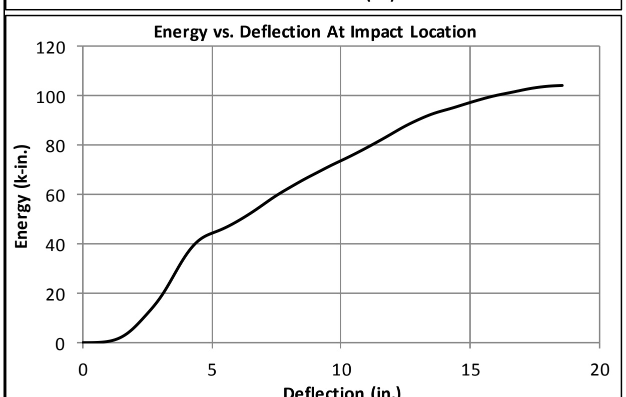
Test Information	Arizona Wood Post	
Test Number:	AZSYP-1	
Test Date:	9-Jul-2012	
Failure Type:	Post rotation in soil and fracture 40" from top	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	72 in.	182.9 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	3.914 @ 15" and 3.491 @ 30"	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.47 mph (31.5 fps)	9.6 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	18.6	in.
Peak Force:	18.5	k
Initial Linear Stiffness:	5.2	k/in.
Total Energy:	104.1	k-in.









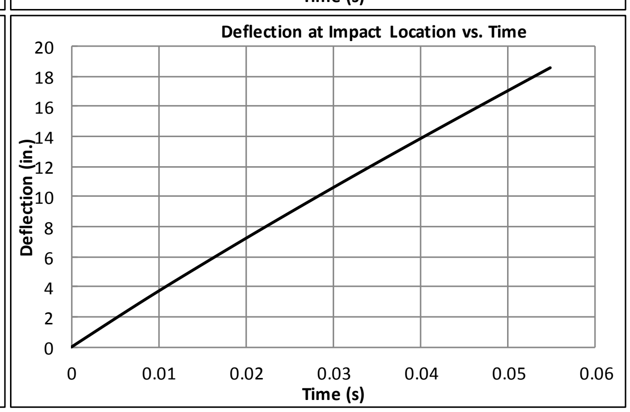


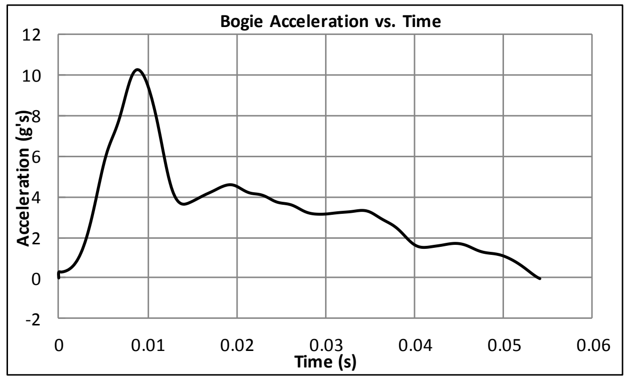
Figure C-1. Results of Test No. AZSYP-1 (DTS-SLICE)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Arizona Wood Post	
Test Number:	AZSYP-1	
Test Date:	9-Jul-2012	
Failure Type:	Post rotation in soil and fracture 40" from top	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	72 in.	182.9 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	3.914 @ 15" and 3.491 @ 30"	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.47 mph (31.5 fps)	9.6 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	18.0	in.
Peak Force:	18.8	k
Initial Linear Stiffness:	5.7	k/in.
Total Energy:	115.6	k-in.



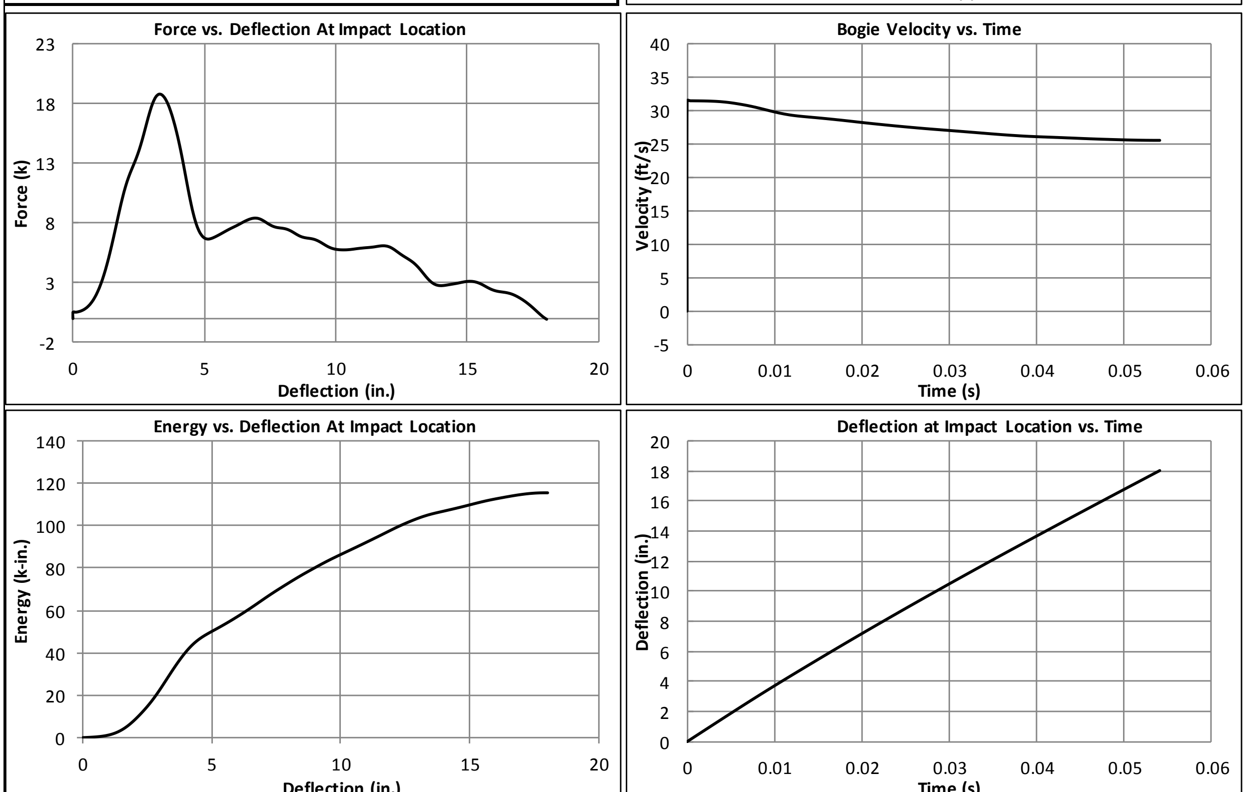


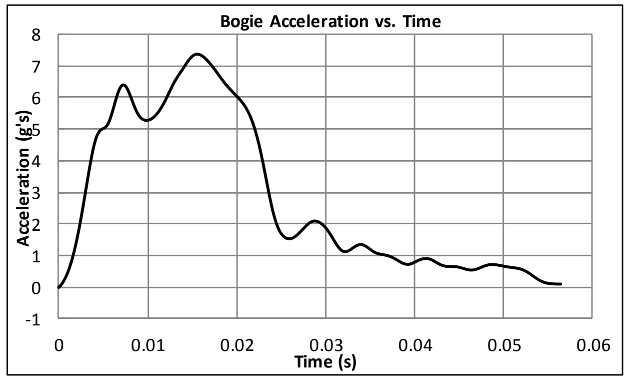
Figure C-2. Results of Test No. AZSYP-1 (EDR-3)

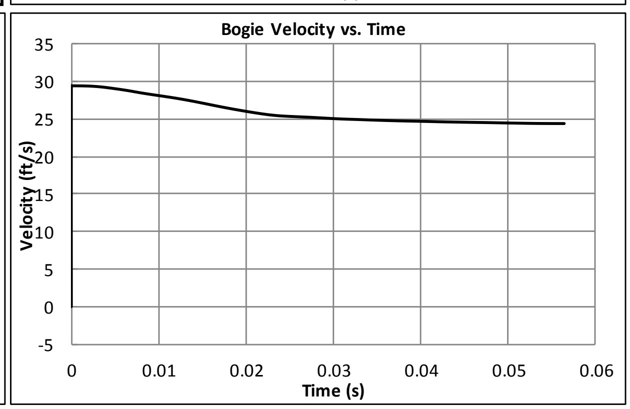
MIDWEST ROADSIDE SAFETY FACILITY

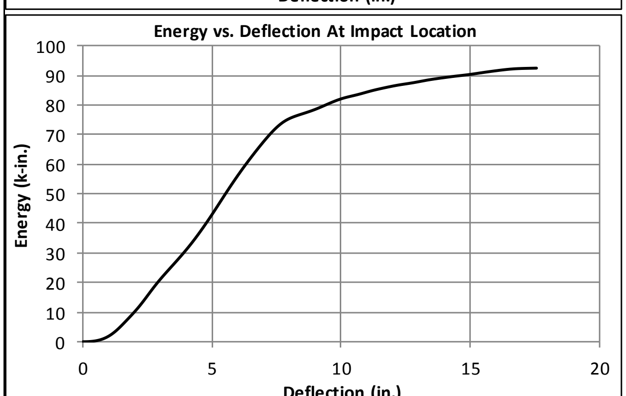
Bogie Test Summary

Test Information	Arizona Wood Post	
Test Number:	AZSYP-2	
Test Date:	10-Jul-2012	
Failure Type:	Post rotation in soil and fracture 42" from top	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	72 in.	182.9 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	15- 3.177% 30-3.9%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.04 mph (29.4 fps)	8.96 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	17.6	in.
Peak Force:	13.5	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	92.4	k-in.







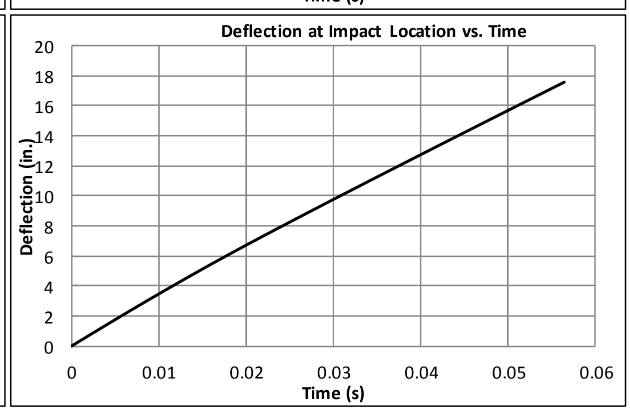


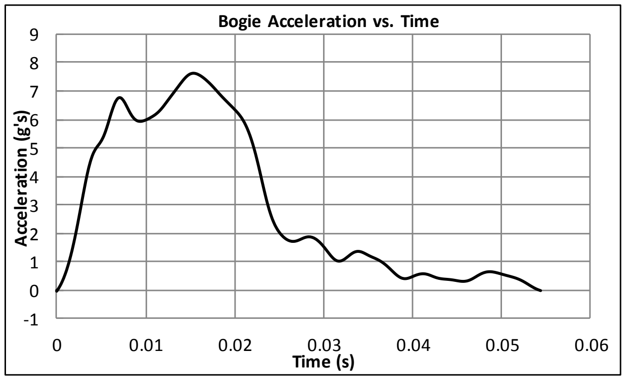
Figure C-3. Results of Test No. AZSYP-2 (DTS-SLICE)

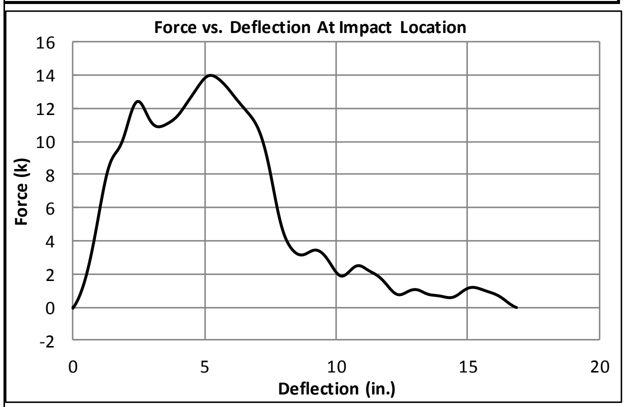
MIDWEST ROADSIDE SAFETY FACILITY

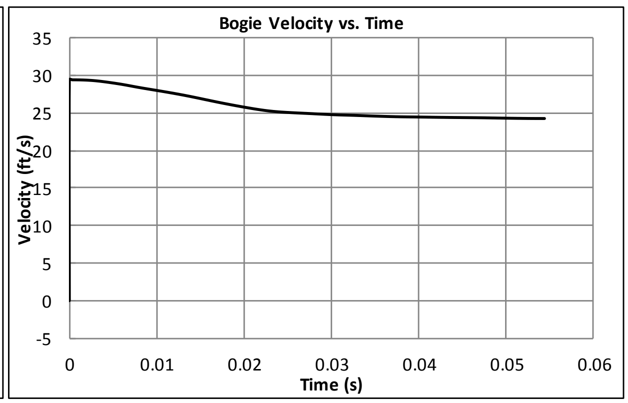
Bogie Test Summary

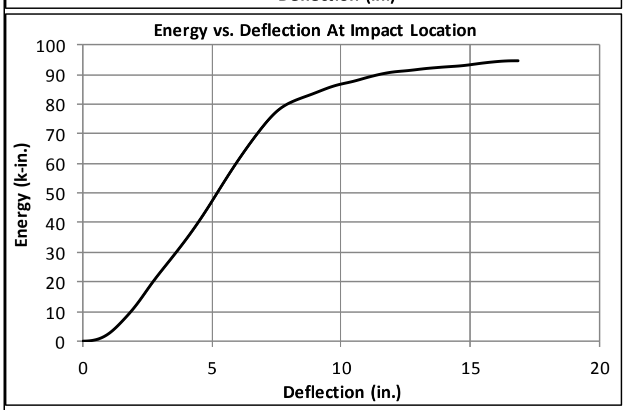
Test Information	Arizona Wood Post	
Test Number:	AZSYP-2	
Test Date:	10-Jul-2012	
Failure Type:	Post rotation in soil and fracture 42" from top	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	72 in.	182.9 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	15- 3.177% 30-3.9%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.04 mph (29.4 fps)	8.96 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	16.9	in.
Peak Force:	14.0	k
Initial Linear Stiffness:	4.9	k/in.
Total Energy:	94.6	k-in.









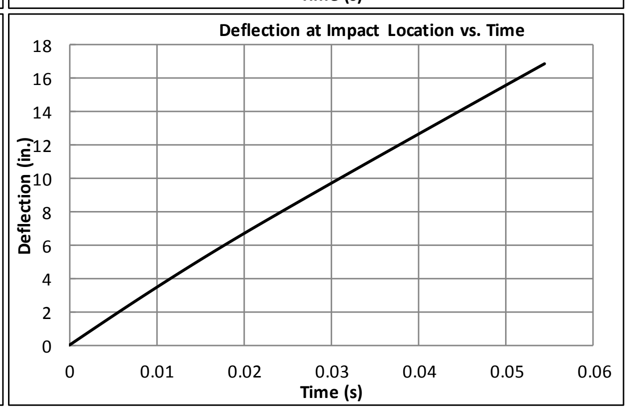


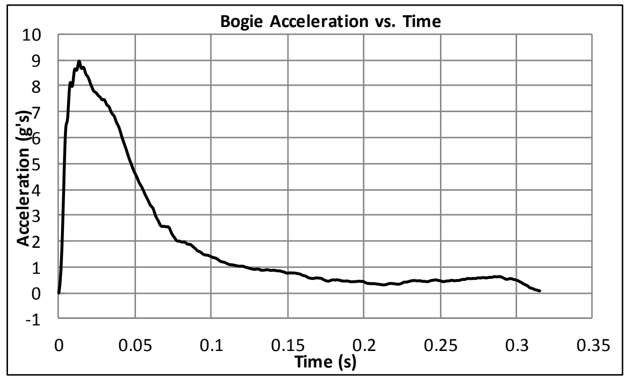
Figure C-4. Results of Test No. AZSYP-2 (EDR-3)

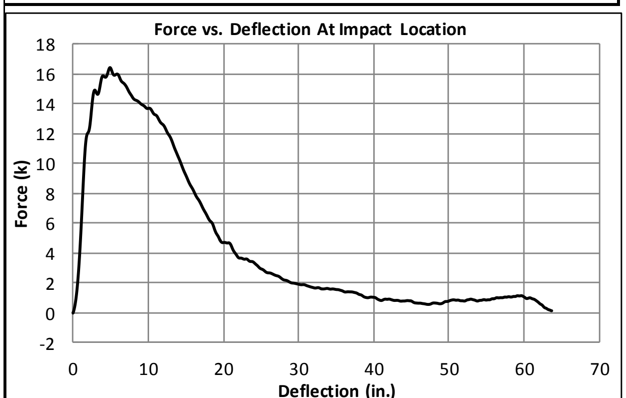
MIDWEST ROADSIDE SAFETY FACILITY

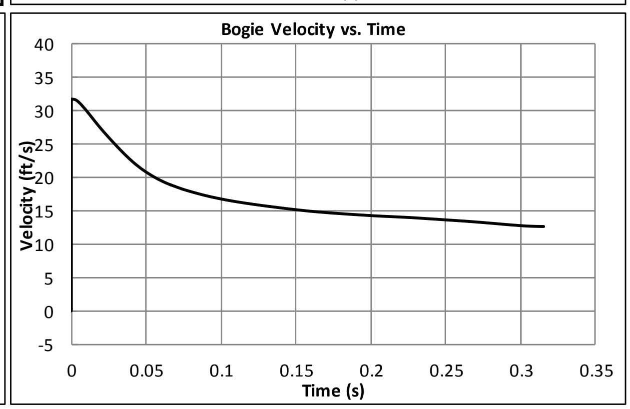
Bogie Test Summary

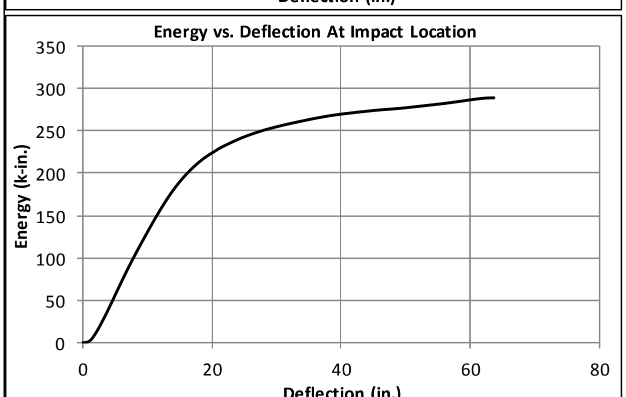
Test Information	Arizona Wood Post	
Test Number:	AZSYP-3	
Test Date:	10-Jul-2012	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	72 in.	182.9 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	15" is 3.062 and 30" is 2.782	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.63 mph (31.7 fps)	9.67 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	63.7	in.
Peak Force:	16.4	k
Initial Linear Stiffness:	3.3	k/in.
Total Energy:	289.1	k-in.









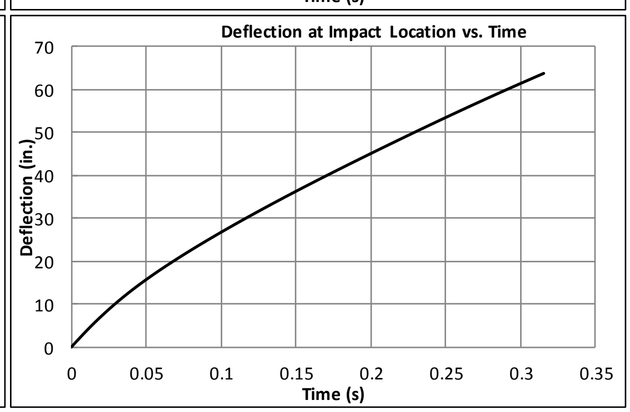


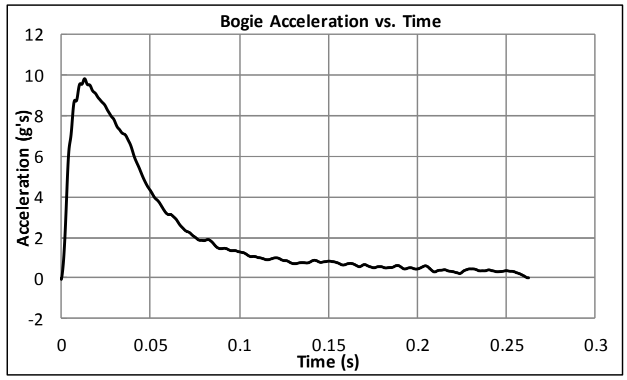
Figure C-5. Results of Test No. AZSYP-3 (DTS-SLICE)

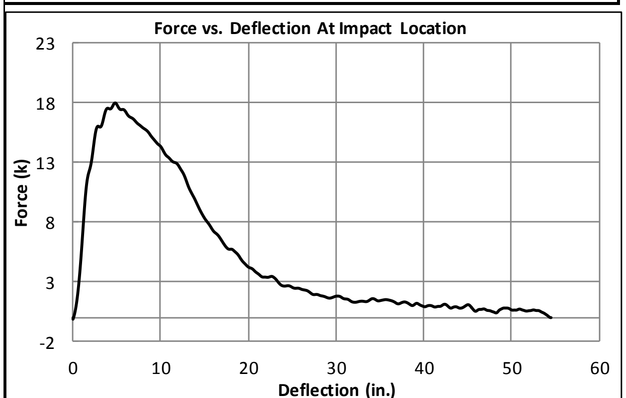
MIDWEST ROADSIDE SAFETY FACILITY

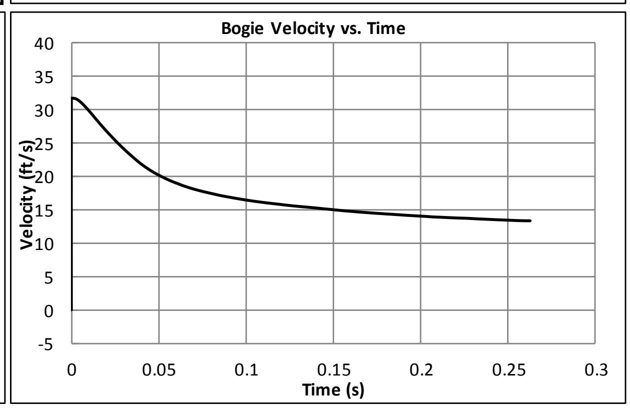
Bogie Test Summary

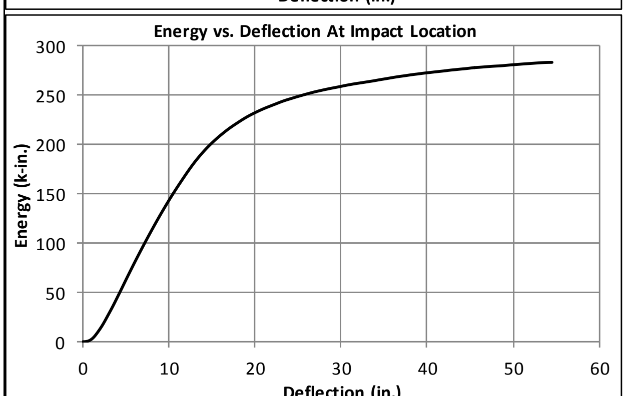
Test Information	Arizona Wood Post	
Test Number:	AZSYP-3	
Test Date:	10-Jul-2012	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	72 in.	182.9 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	15" is 3.062 and 30" is 2.782	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.63 mph (31.7 fps)	9.67 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	54.5	in.
Peak Force:	18.0	k
Initial Linear Stiffness:	3.7	k/in.
Total Energy:	283.1	k-in.









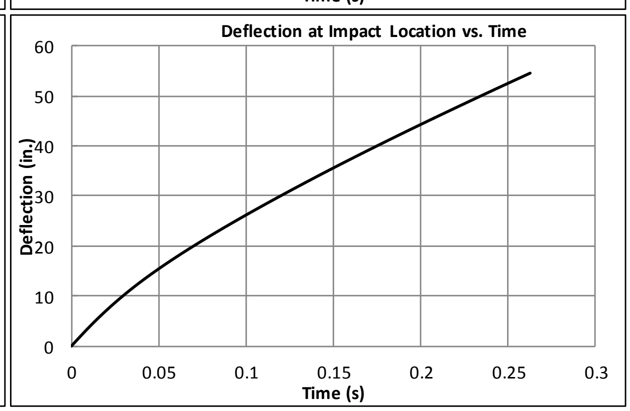


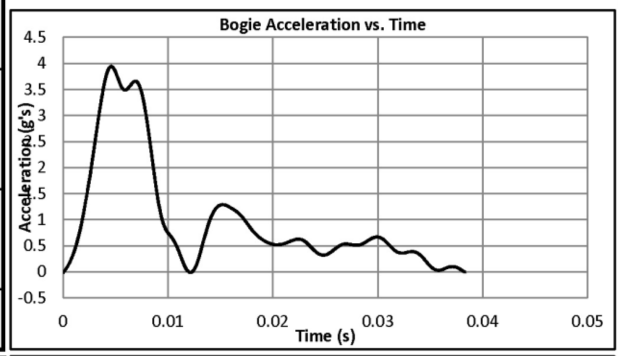
Figure C-6. Results of Test No. AZSYP-3 (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Arizona Wood Post	
Test Number:	AZSYP-4	
Test Date:	10-Jul-2012	
Failure Type:	Post rotation in soil and fracture	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	15" @ 2.941 and 30" @ 2.872	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.51 mph (28.6 fps)	8.72 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	12.8	in.
Peak Force:	7.2	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	23.5	k-in.



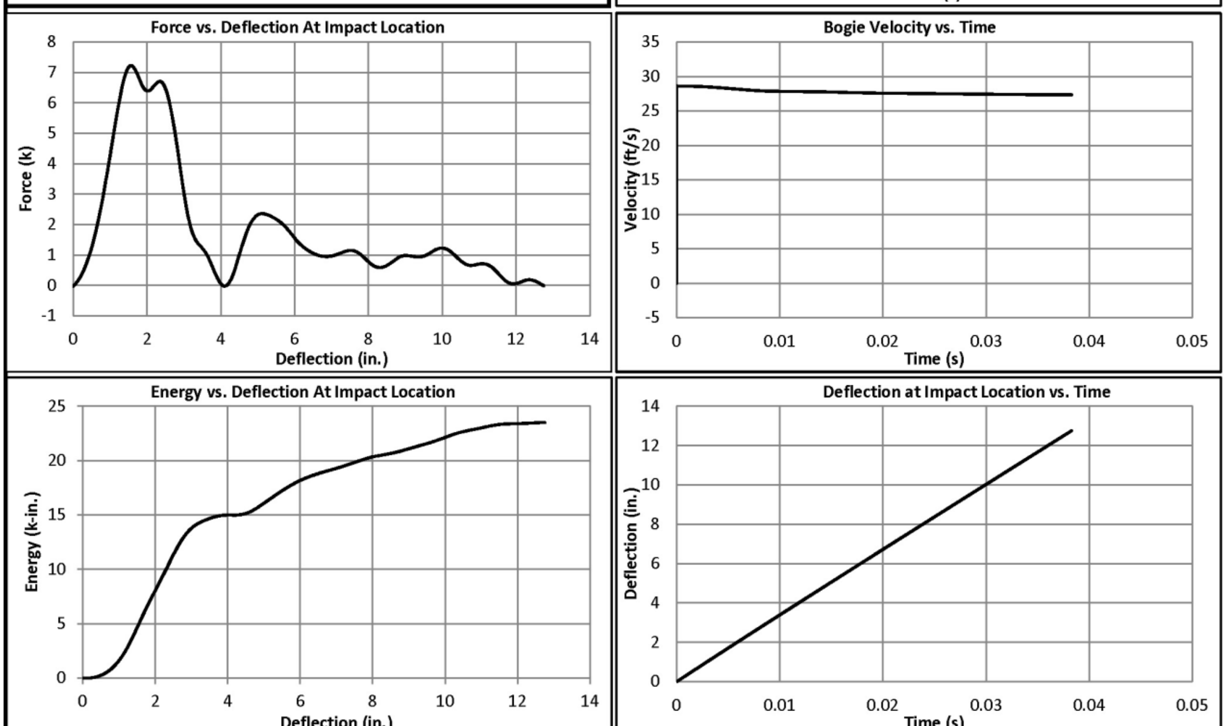


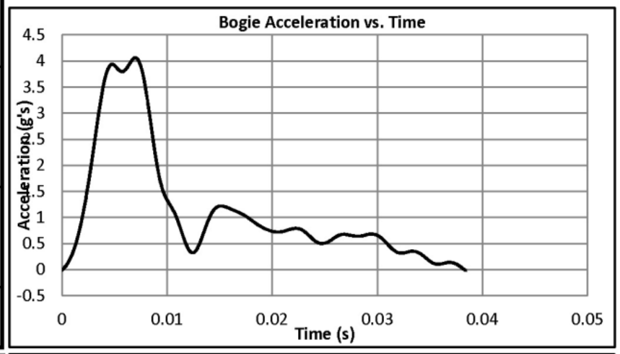
Figure C-7. Results of Test No. AZSYP-4 (DTS-SLICE)

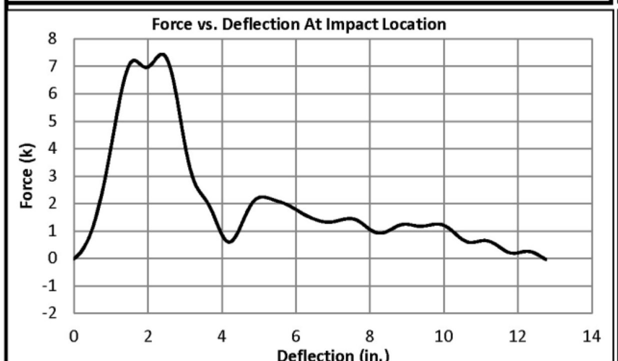
MIDWEST ROADSIDE SAFETY FACILITY

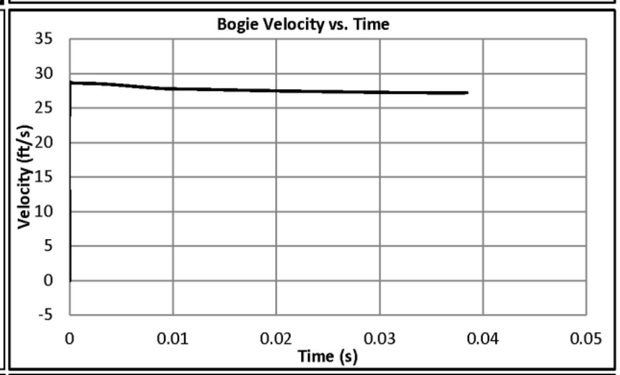
Bogie Test Summary

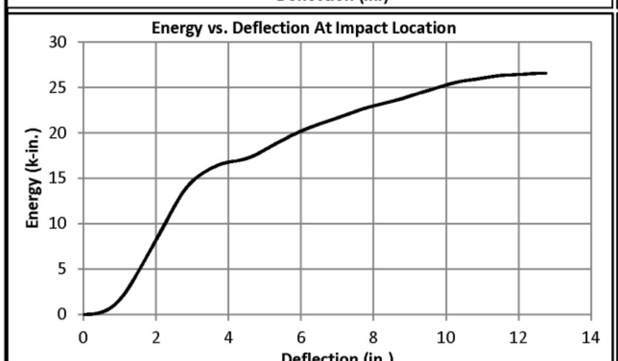
Test Information	Arizona Wood Post	
Test Number:	AZSYP-4	
Test Date:	10-Jul-2012	
Failure Type:	Post rotation in soil and fracture	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	15" @ 2.941 and 30" @ 2.872	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.51 mph (28.6 fps)	8.72 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	12.8	in.
Peak Force:	7.4	k
Initial Linear Stiffness:	3.2	k/in.
Total Energy:	26.6	k-in.









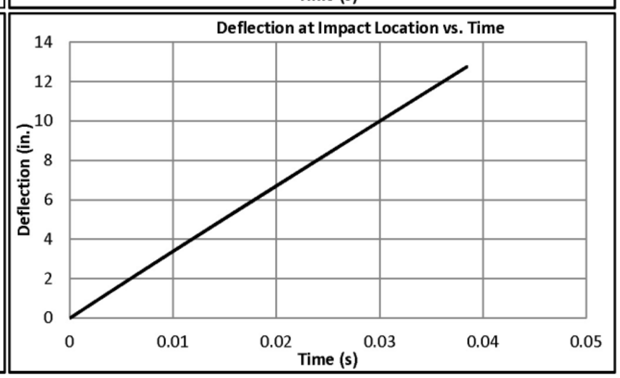


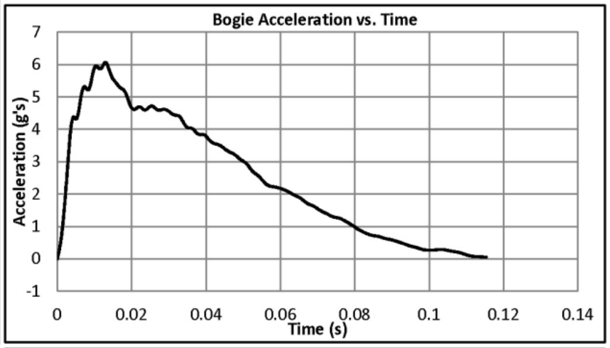
Figure C-8. Results of Test No. AZSYP-4 (EDR-3)

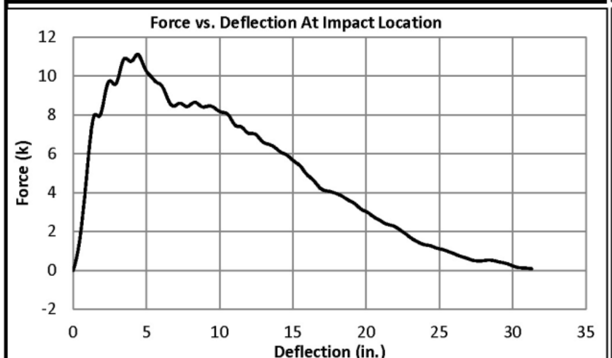
MIDWEST ROADSIDE SAFETY FACILITY

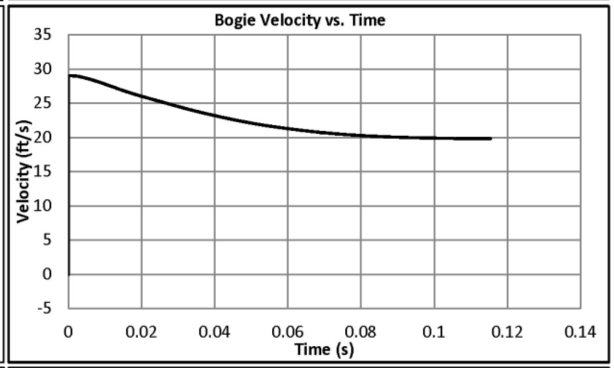
Bogie Test Summary

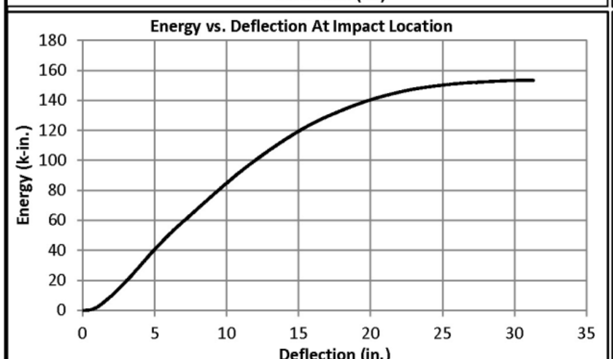
Test Information	Arizona Wood Post	
Test Number:	AZSYP-5	
Test Date:	11-Jul-2012	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	3.001/2.995%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.77 mph (29 fps)	8.84 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	31.3	in.
Peak Force:	11.1	k
Initial Linear Stiffness:	2.5	k/in.
Total Energy:	153.5	k-in.









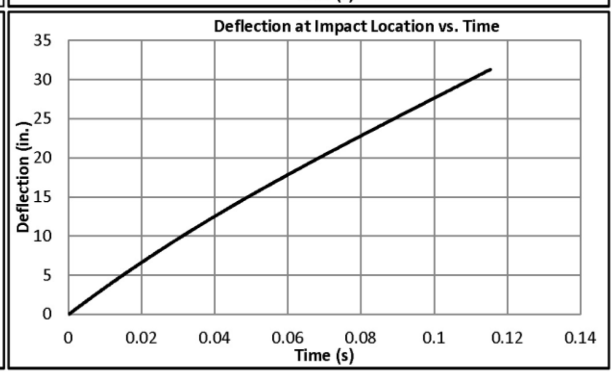


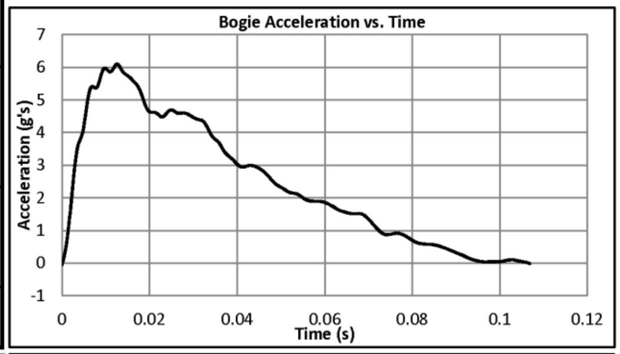
Figure C-9. Results of Test No. AZSYP-5 (DTS-SLICE)

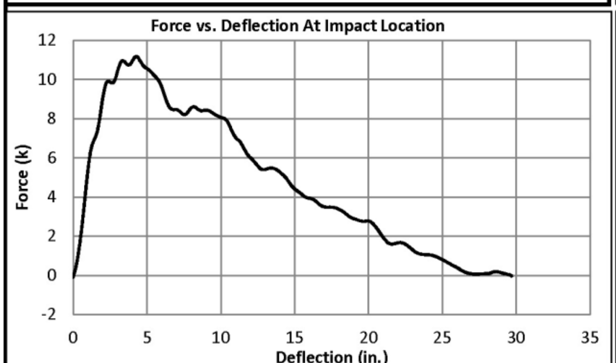
MIDWEST ROADSIDE SAFETY FACILITY

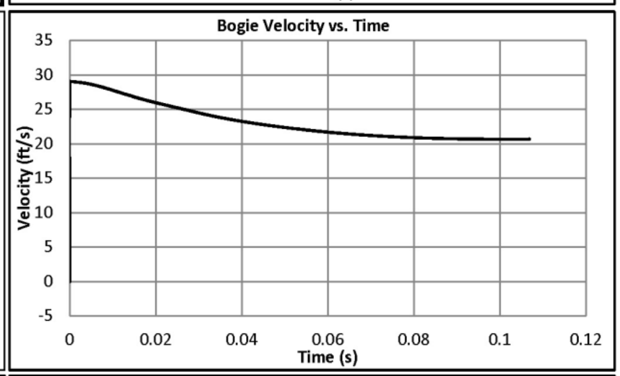
Bogie Test Summary

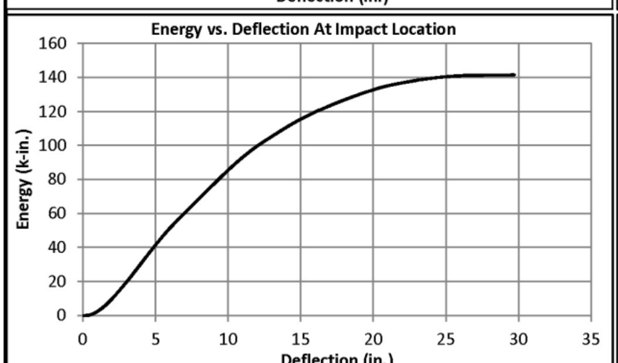
Test Information	Arizona Wood Post	
Test Number:	AZSYP-5	
Test Date:	11-Jul-2012	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	3.001/2.995%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.77 mph (29 fps)	8.84 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	29.7	in.
Peak Force:	11.2	k
Initial Linear Stiffness:	2.6	k/in.
Total Energy:	141.6	k-in.









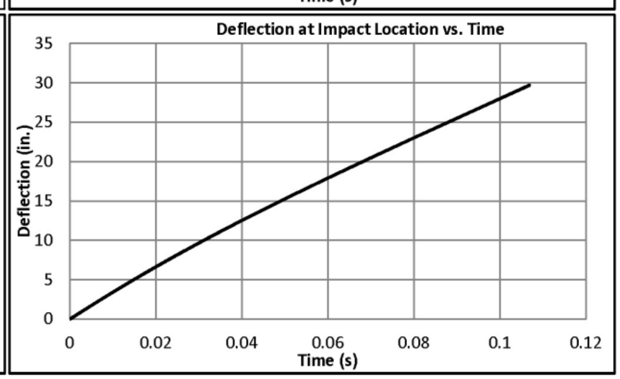


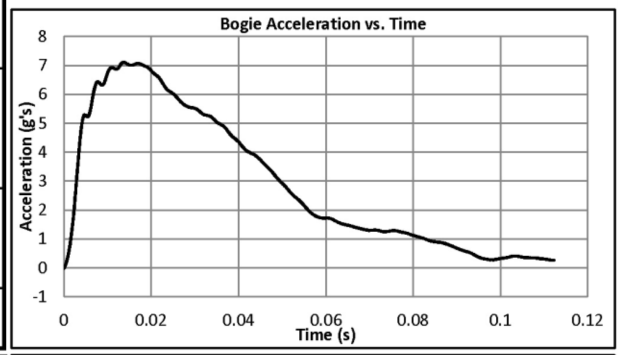
Figure C-10. Results of Test No. AZSYP-5 (EDR-3)

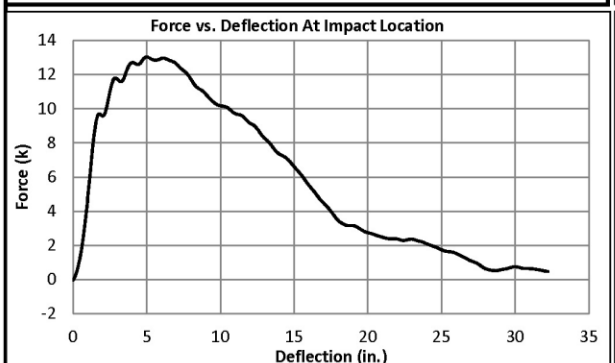
MIDWEST ROADSIDE SAFETY FACILITY

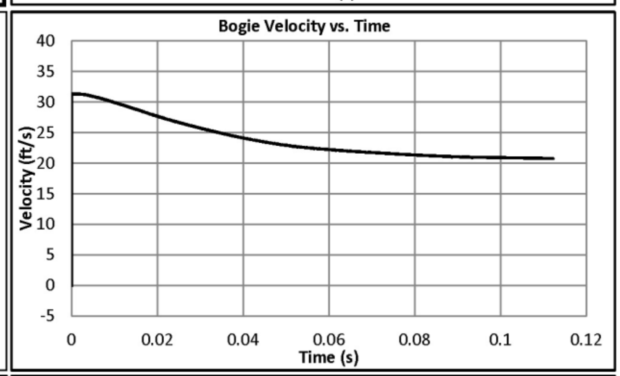
Bogie Test Summary

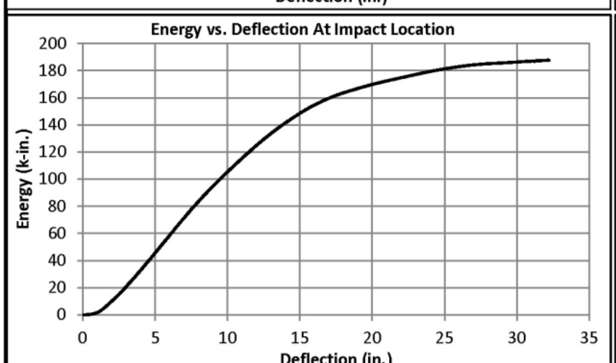
Test Information	Arizona Wood Post	
Test Number:	AZSYP-6	
Test Date:	11-Jul-2012	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	3.373% / 2.570%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.36 mph (31.3 fps)	9.55 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	32.2	in.
Peak Force:	13.0	k
Initial Linear Stiffness:	2.6	k/in.
Total Energy:	187.7	k-in.









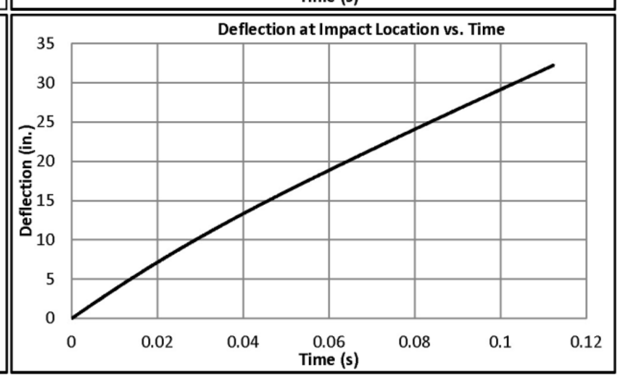


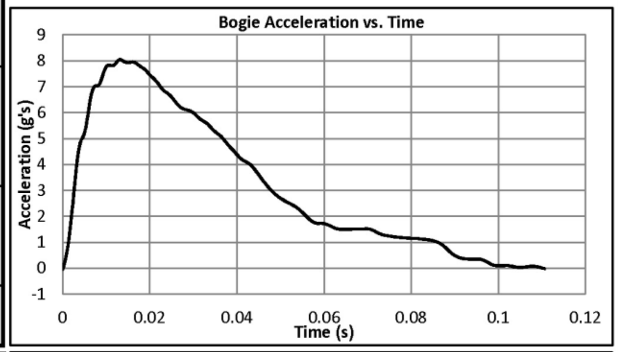
Figure C-11. Results of Test No. AZSYP-6 (DTS-SLICE)

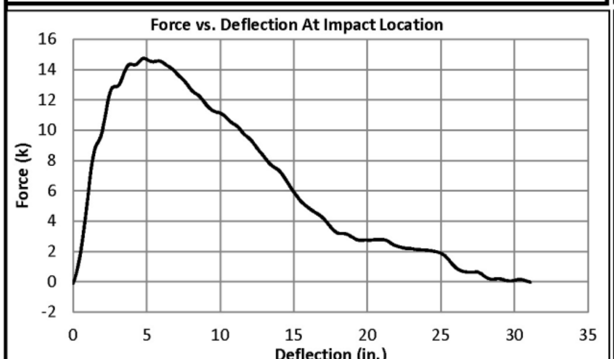
MIDWEST ROADSIDE SAFETY FACILITY

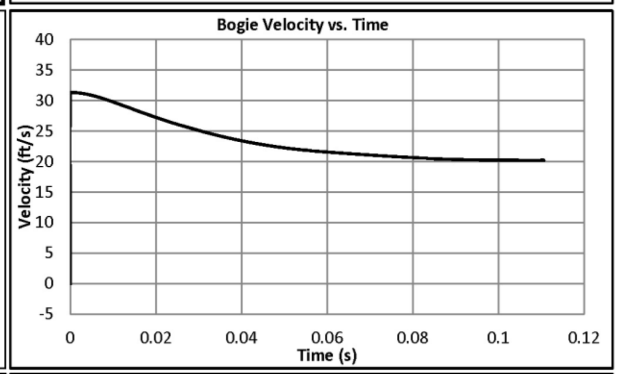
Bogie Test Summary

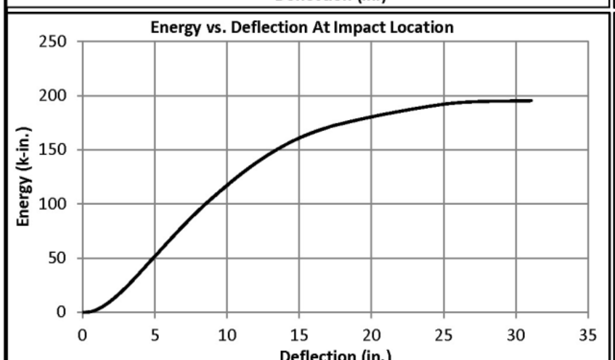
Test Information	Arizona Wood Post	
Test Number:	AZSYP-6	
Test Date:	11-Jul-2012	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	Rectangular Southern Yellow Pine	
Post Size:	6"x8"	152x203
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	1192012	
Moisture Content:	3.373% / 2.570%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.36 mph (31.3 fps)	9.55 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1832.8 lbs	831.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5	

Test Results Summary		
Max. Deflection:	31.1	in.
Peak Force:	14.7	k
Initial Linear Stiffness:	3.1	k/in.
Total Energy:	195.3	k-in.









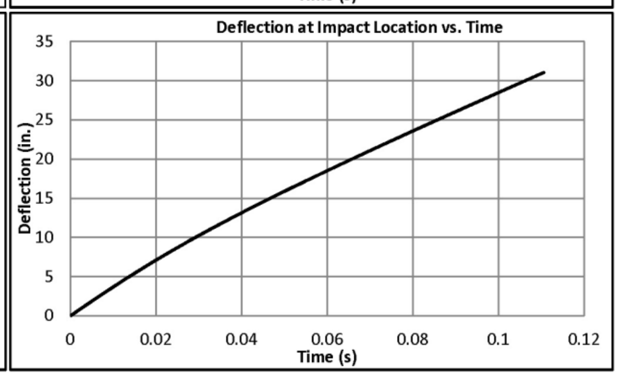


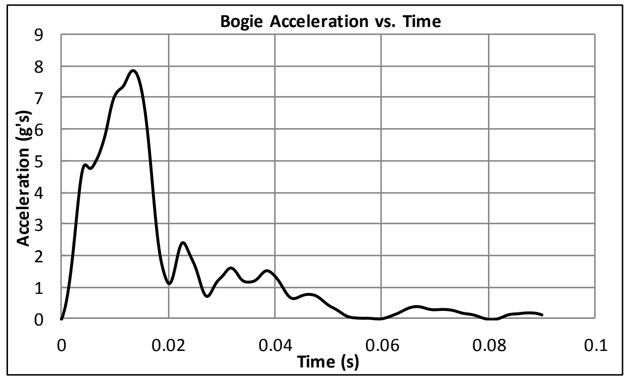
Figure C-12. Results of Test No. AZSYP-6 (EDR-3)

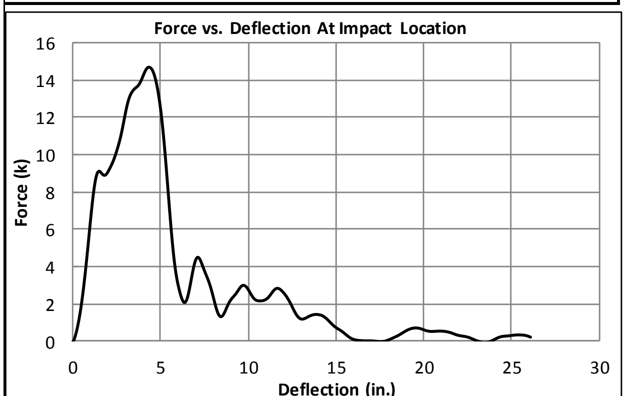
MIDWEST ROADSIDE SAFETY FACILITY

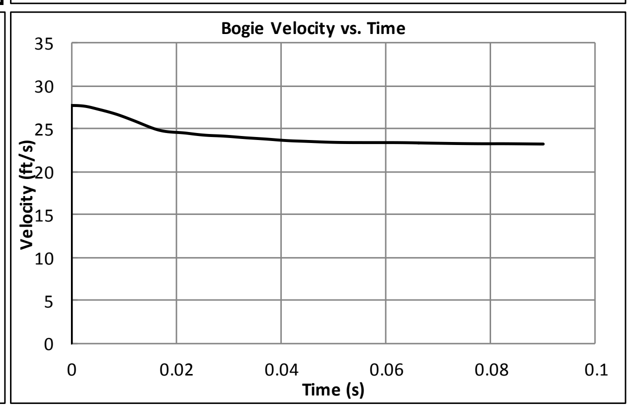
Bogie Test Summary

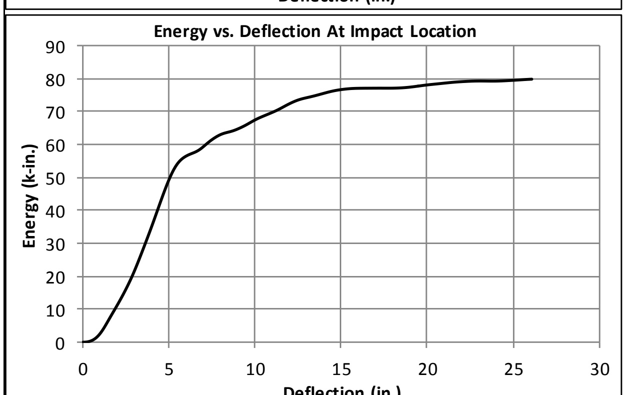
Test Information	Arizona Wood Post	
Test Number:	AZPP-1	
Test Date:	7-Aug-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.48" dia.	215 mm dia.
Post Length:	66 in.	167.6 cm
Embedment Depth:	37 in.	94 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.5% @15" / 3.0% @30"%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.88 mph (27.7 fps)	8.44 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1872.6 lbs	849.4 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5 @ 270"	

Test Results Summary		
Max. Deflection:	16.0	in.
Peak Force:	14.7	k
Initial Linear Stiffness:	3.4	k/in.
Total Energy:	77.1	k-in.









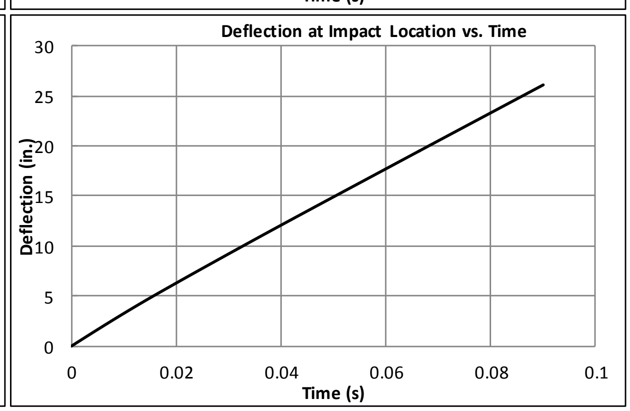


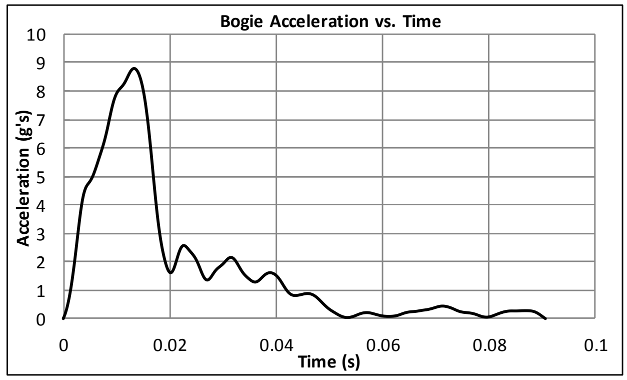
Figure C-13. Results of Test No. AZPP-1 (DTS-SLICE)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Arizona Wood Post	
Test Number:	AZPP-1	
Test Date:	7-Aug-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.48" dia.	215 mm dia.
Post Length:	66 in.	167.6 cm
Embedment Depth:	37 in.	94 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.9% / 4.1%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.88 mph (27.7 fps)	8.44 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1872.6 lbs	849.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 @ 270"	

Test Results Summary		
Max. Deflection:	15.6	in.
Peak Force:	16.5	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	86.7	k-in.



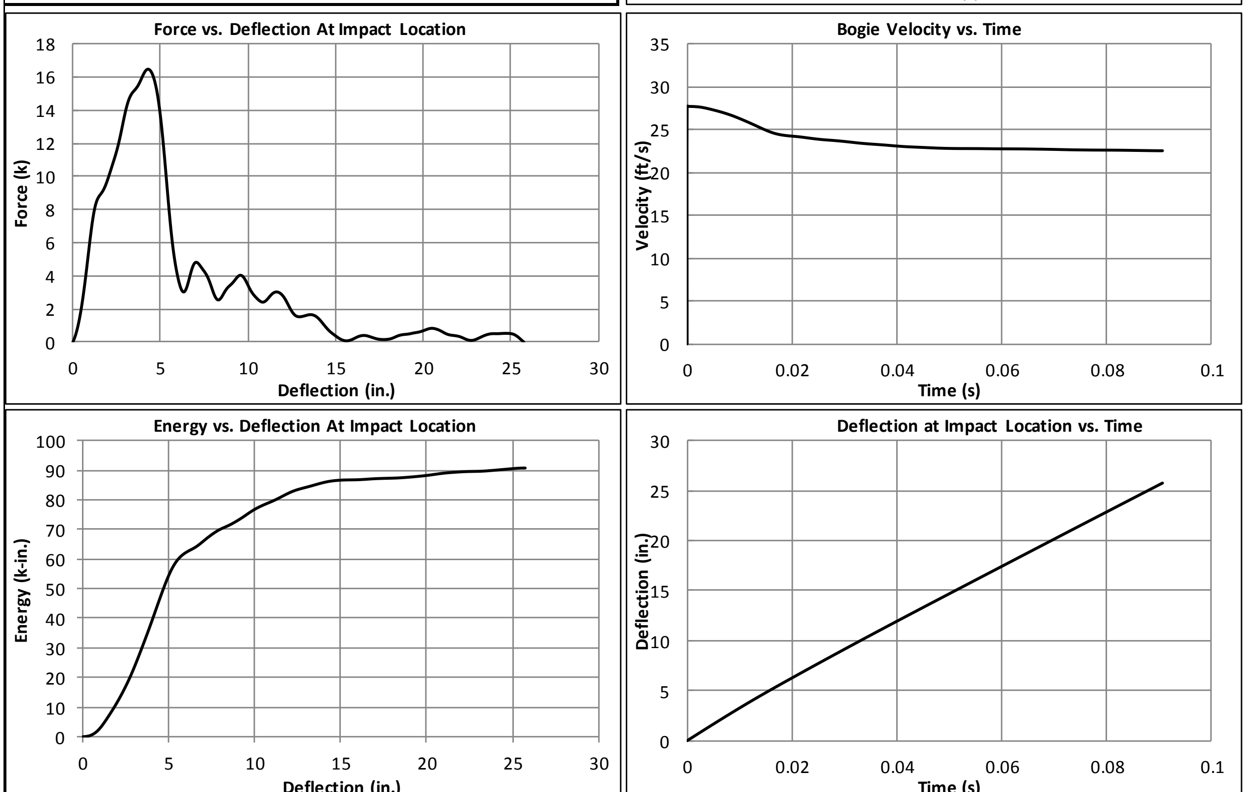


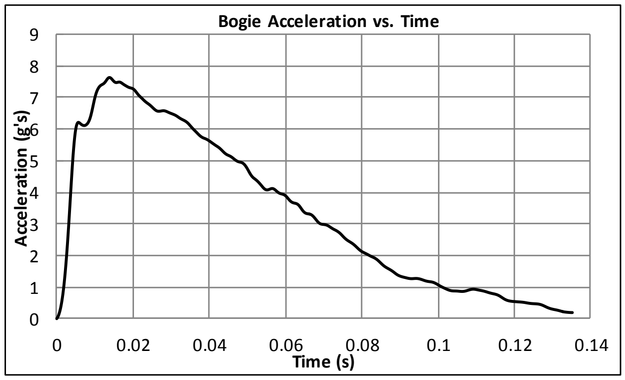
Figure C-14. Results of Test No. AZPP-1 (EDR-3)

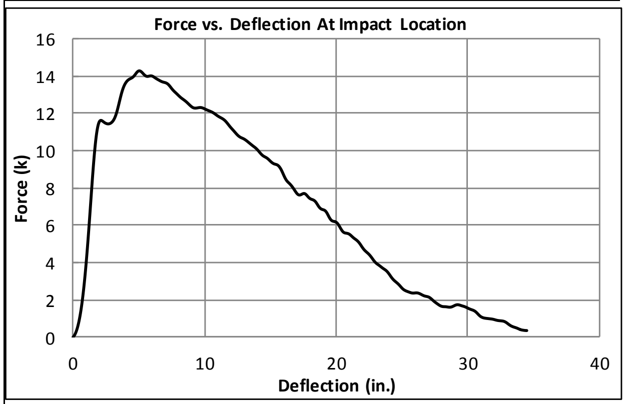
MIDWEST ROADSIDE SAFETY FACILITY

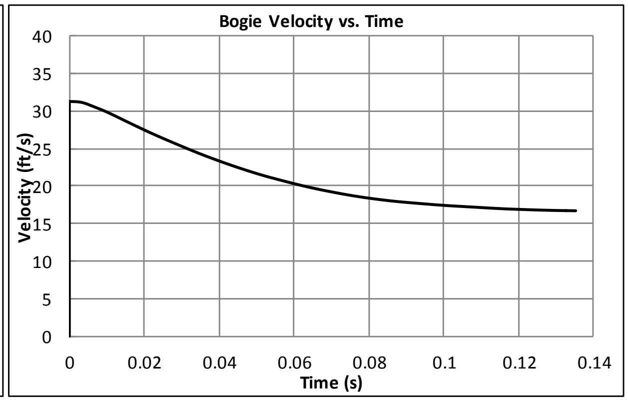
Bogie Test Summary

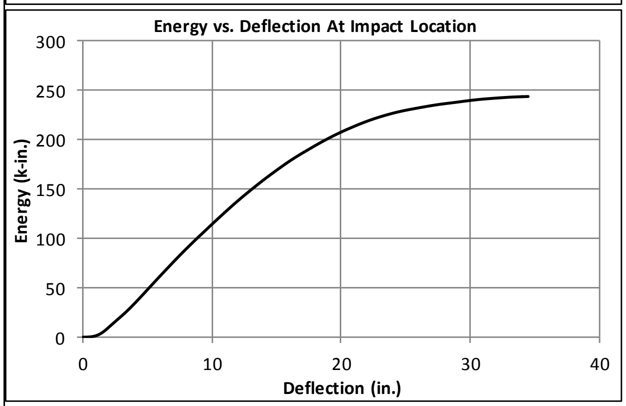
Test Information	Arizona Wood Post	
Test Number:	AZPP-2	
Test Date:	8-Aug-2012	
Failure Type:	Post Rotation Through Soil	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.67" dia.	220 mm dia.
Post Length:	66 in.	167.6 cm
Embedment Depth:	37 in.	94 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.5% @15" / 3.0% @30"%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.32 mph (31.3 fps)	9.53 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1872.6 lbs	849.4 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5 @ 255"	

Test Results Summary		
Max. Deflection:	34.5	in.
Peak Force:	14.3	k
Initial Linear Stiffness:	2.8	k/in.
Total Energy:	243.5	k-in.









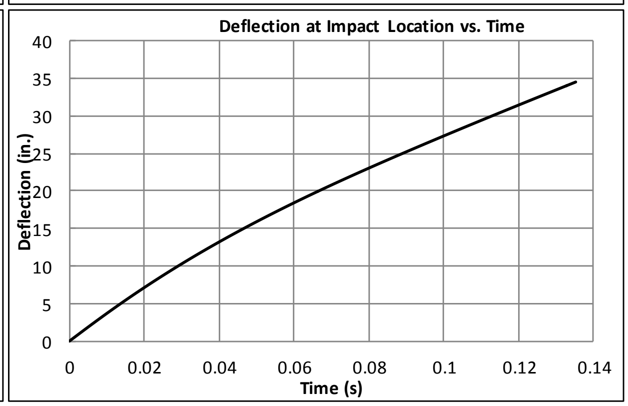


Figure C-15. Results of Test No. AZPP-2 (DTS-SLICE)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information Arizona Wood Post

Test Number:	AZPP-2	
Test Date:	8-Aug-2012	
Failure Type:	Post Rotation Through Soil	

Post Properties

Post Type:	Round Ponderosa Pine	
Post Size:	8.67" dia.	220 mm dia.
Post Length:	66 in.	167.6 cm
Embedment Depth:	37 in.	94 cm
Orientation:	NA	

Soil Properties

Gradation:	1/19/2012
Moisture Content:	3.5% @15" / 3.0% @30"%
Compaction Method:	HE8
Soil Density, γd:	NA

Bogie Properties

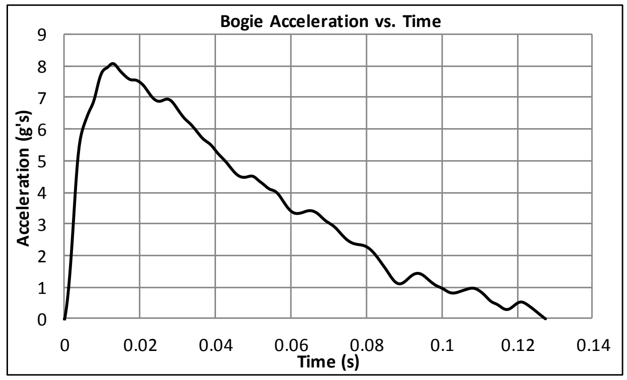
Impact Velocity:	21.32 mph (31.3 fps)	9.53 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1872.6 lbs	849.4 kg

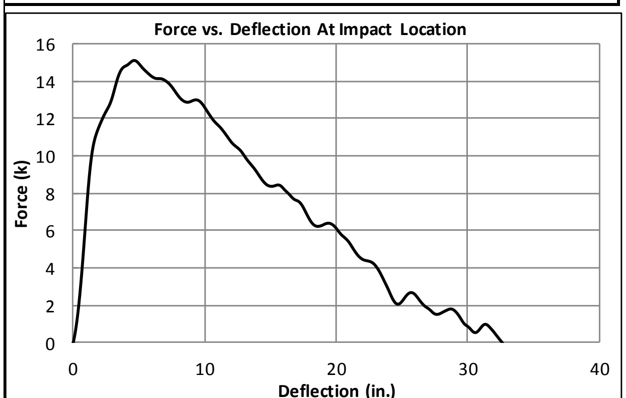
Data Acquired

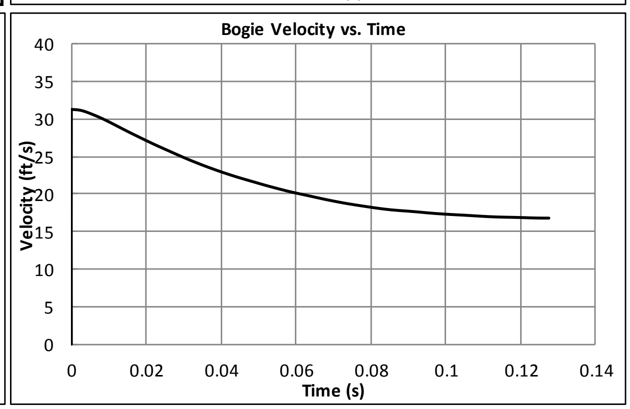
Acceleration Data:	EDR-3
Camera Data:	AOS-5 @ 255"

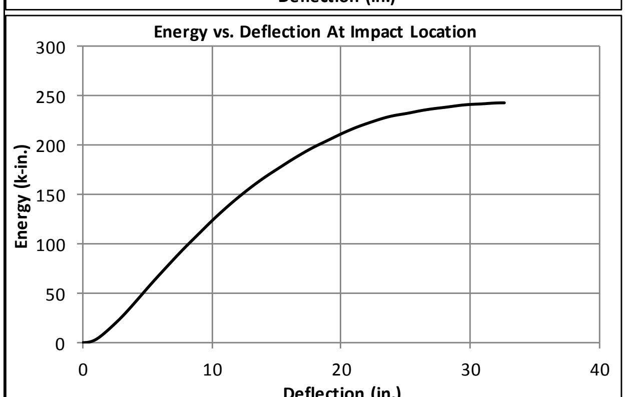
Test Results Summary

Max. Deflection:	32.7	in.
Peak Force:	15.1	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	242.7	k-in.









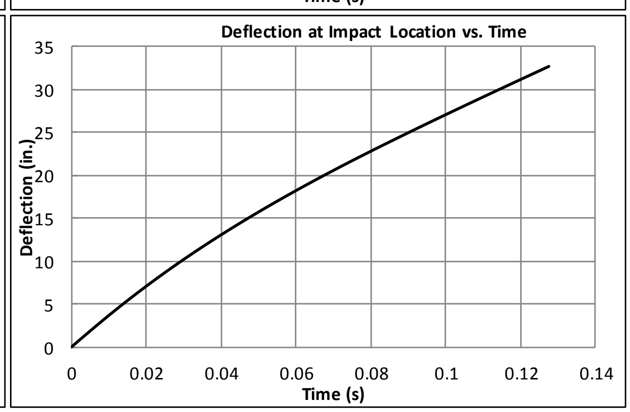


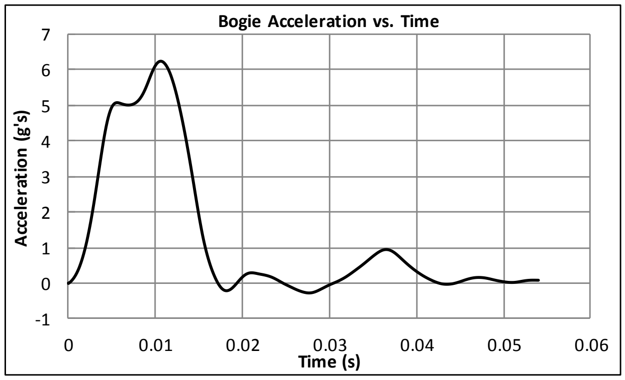
Figure C-16. Results of Test No. AZPP-2 (EDR-3)

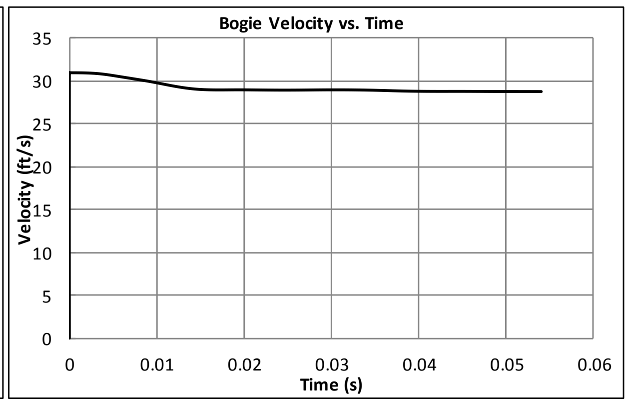
MIDWEST ROADSIDE SAFETY FACILITY

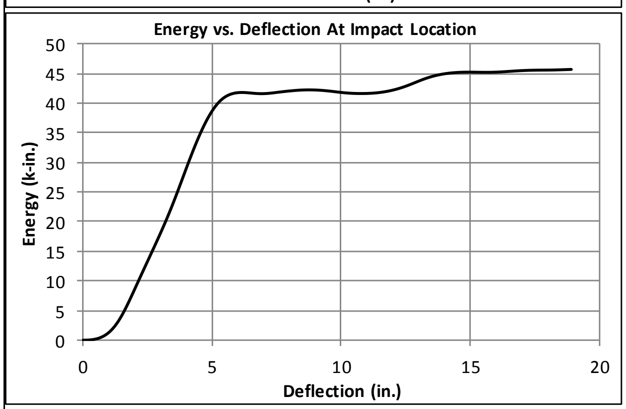
Bogie Test Summary

Test Information	Arizona Wood Post	
Test Number:	AZPP-3	
Test Date:	8-Aug-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.48" dia.	215 mm dia.
Post Length:	66 in.	167.6 cm
Embedment Depth:	37 in.	94 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	2.7% / 2.9%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.09 mph (30.9 fps)	9.43 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1872.6 lbs	849.4 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5 @ 255"	

Test Results Summary		
Max. Deflection:	5.7	in.
Peak Force:	11.7	k
Initial Linear Stiffness:	3.0	k/in.
Total Energy:	41.4	k-in.







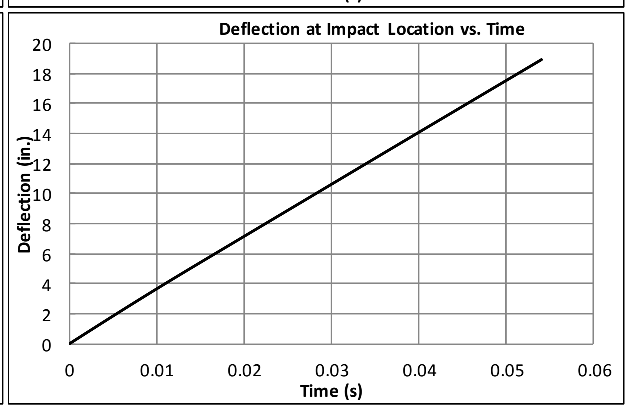


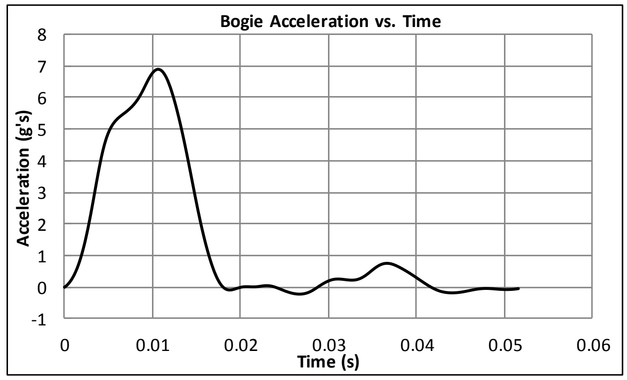
Figure C-17. Results of Test No. AZPP-3 (DTS-SLICE)

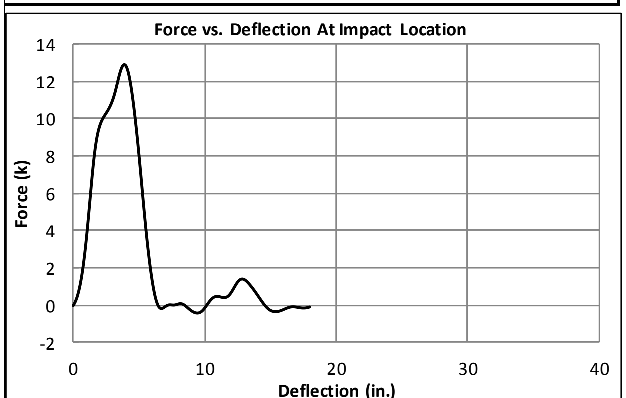
MIDWEST ROADSIDE SAFETY FACILITY

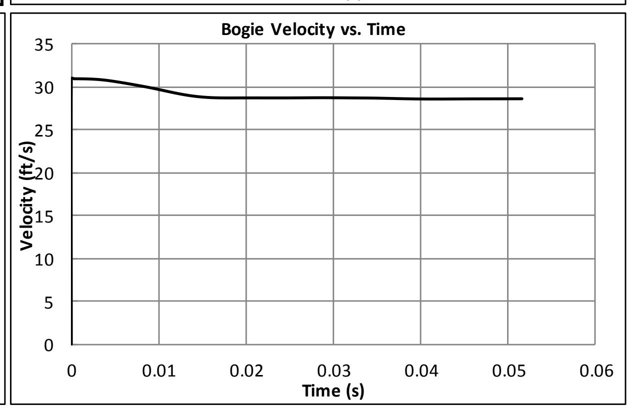
Bogie Test Summary

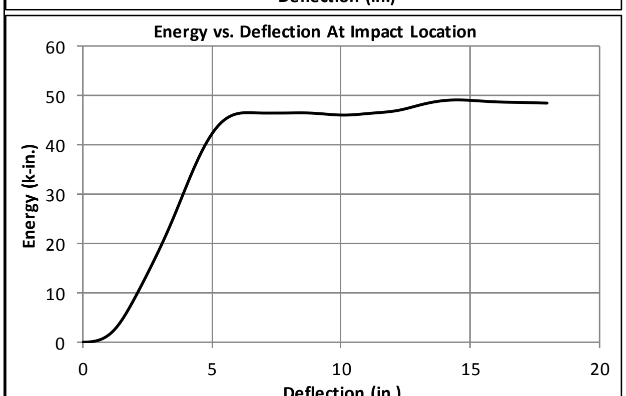
Test Information	Arizona Wood Post	
Test Number:	AZPP-3	
Test Date:	8-Aug-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.48" dia.	215 mm dia.
Post Length:	66 in.	167.6 cm
Embedment Depth:	37 in.	94 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	2.7% / 2.9%	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.09 mph (30.9 fps)	9.43 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1872.6 lbs	849.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 @ 255"	

Test Results Summary		
Max. Deflection:	6.5	in.
Peak Force:	12.9	k
Initial Linear Stiffness:	3.6	k/in.
Total Energy:	46.5	k-in.









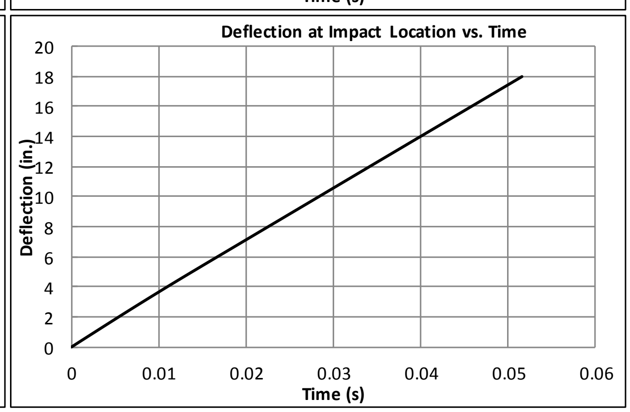


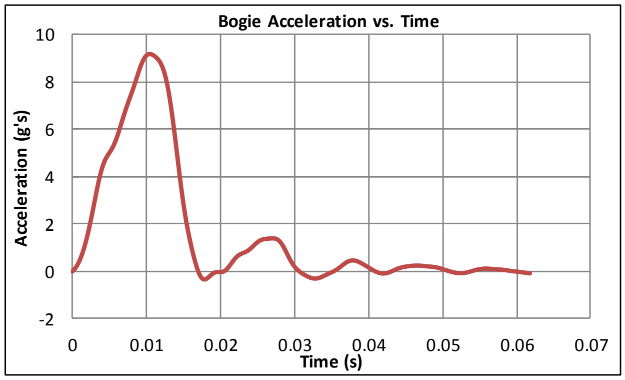
Figure C-18. Results of Test No. AZPP-3 (EDR-3)

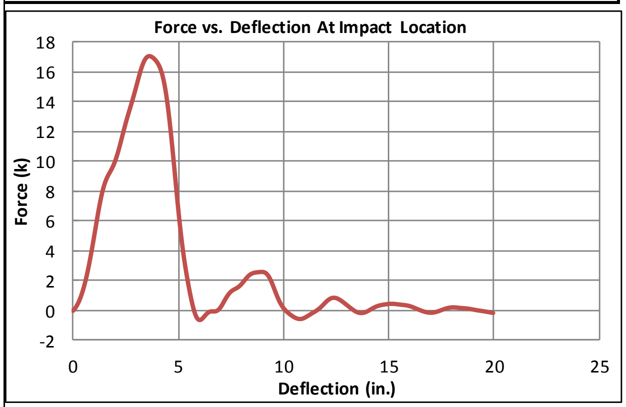
MIDWEST ROADSIDE SAFETY FACILITY

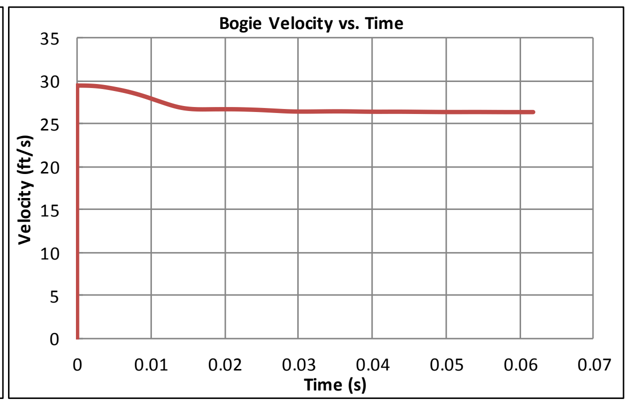
Bogie Test Summary

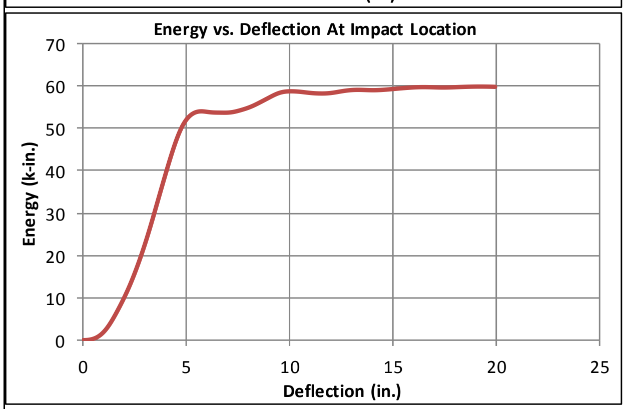
Test Information	Bogie - Post in Soil	
Test Number:	AZPP-4	
Test Date:	25-Sep-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Ponderosa Pine	
Post Size:	8.55" dia.	216 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	4.3% @ 15" - 3.9% @ 30"	
Compaction Method:	HE- 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.07 mph (29.4 fps)	8.97 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5 Perpendicular - 271"	

Test Results Summary		
Max. Deflection:	5.8	in.
Peak Force:	17.0	k
Initial Linear Stiffness:	4.7	k/in.
Total Energy:	59.9	k-in.









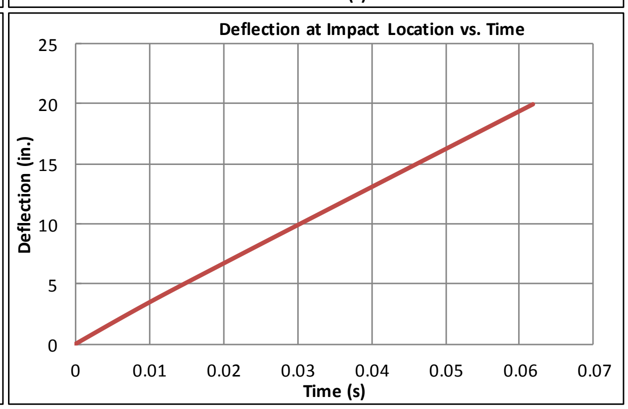


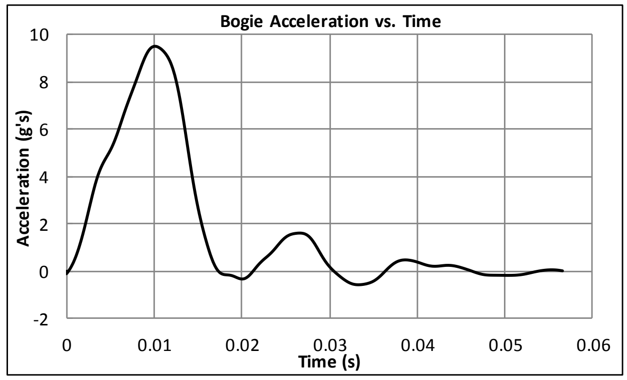
Figure C-19. Results of Test No. AZPP-4 (DTS-SLICE)

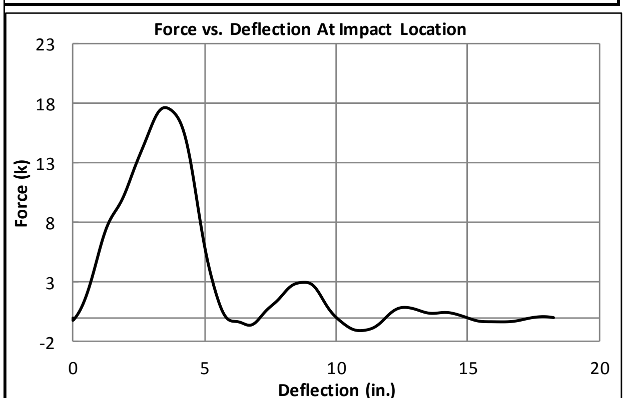
MIDWEST ROADSIDE SAFETY FACILITY

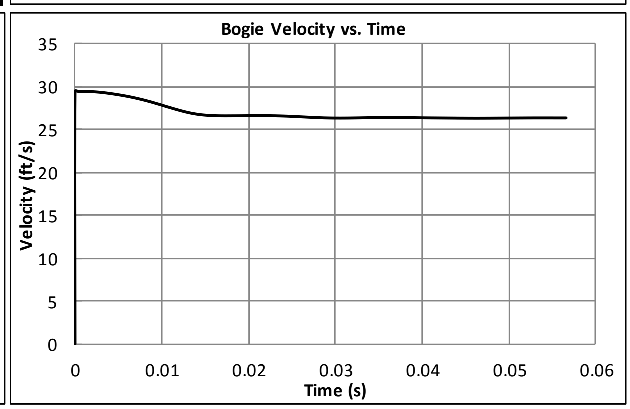
Bogie Test Summary

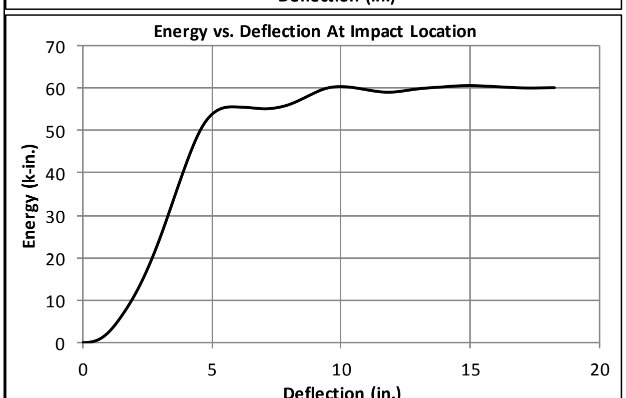
Test Information	Bogie - Post in Soil	
Test Number:	AZPP-4	
Test Date:	25-Sep-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Ponderosa Pine	
Post Size:	8.55" dia.	216 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	4.3% @ 15" - 3.9% @ 30"	
Compaction Method:	HE- 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.07 mph (29.4 fps)	8.97 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 271"	

Test Results Summary		
Max. Deflection:	5.9	in.
Peak Force:	17.6	k
Initial Linear Stiffness:	5.1	k/in.
Total Energy:	60.6	k-in.









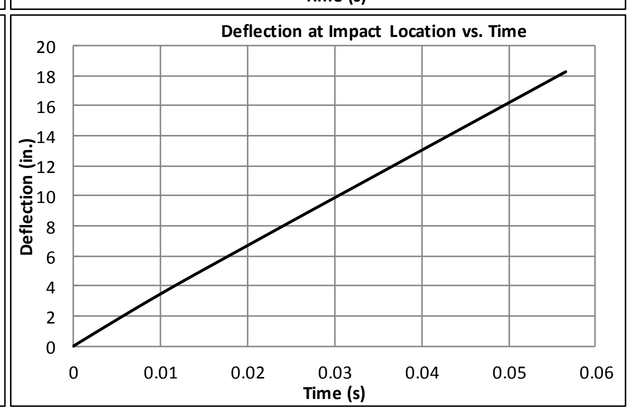


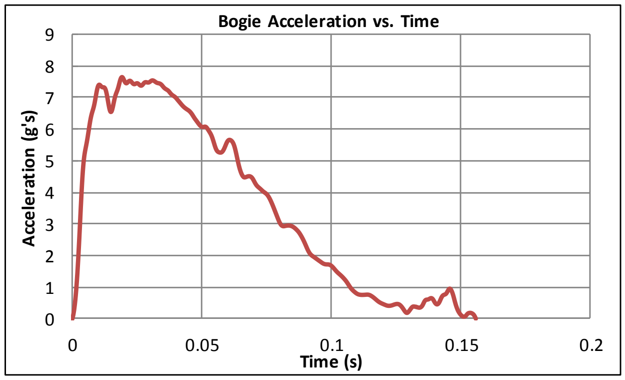
Figure C-20. Results of Test No. AZPP-4 (EDR-3)

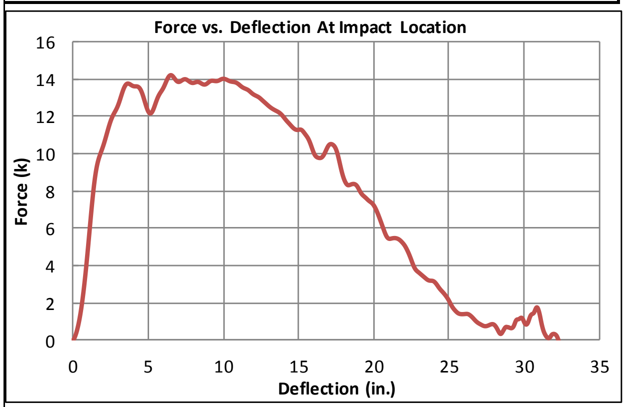
MIDWEST ROADSIDE SAFETY FACILITY

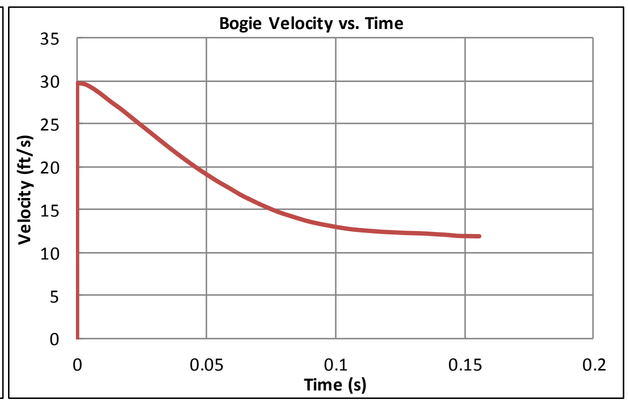
Bogie Test Summary

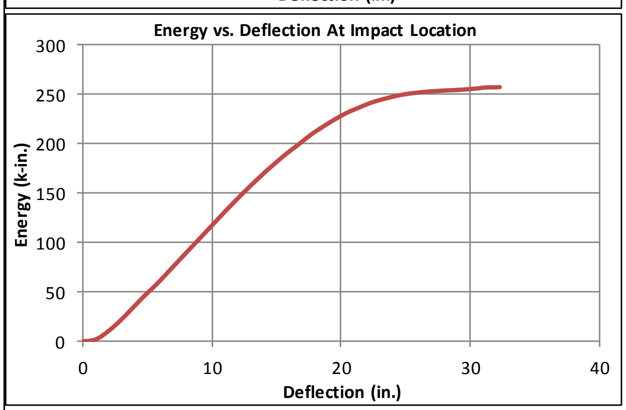
Test Information	Bogie - Post in Soil	
Test Number:	AZPP-5	
Test Date:	25-Sep-2012	
Failure Type:	Rotation Through Soil	
Post Properties		
Post Type:	Ponderosa Pine	
Post Size:	8.55" dia.	216 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.7% @ 15" - 3.5% @ 30"	
Compaction Method:	HE- 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.24 mph (29.7 fps)	9.05 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5 Perpendicular - 273"	

Test Results Summary		
Max. Deflection:	32.3	in.
Peak Force:	14.2	k
Initial Linear Stiffness:	2.2	k/in.
Total Energy:	257.0	k-in.









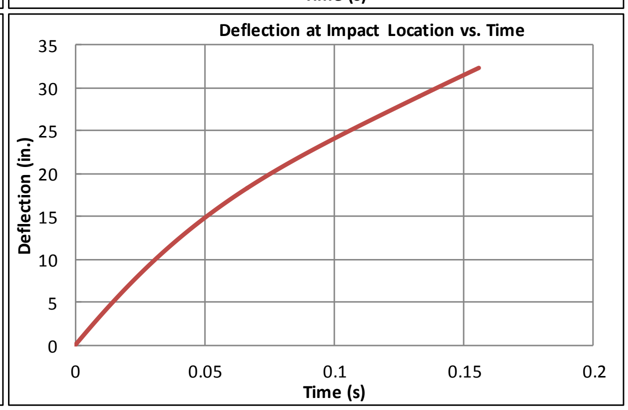


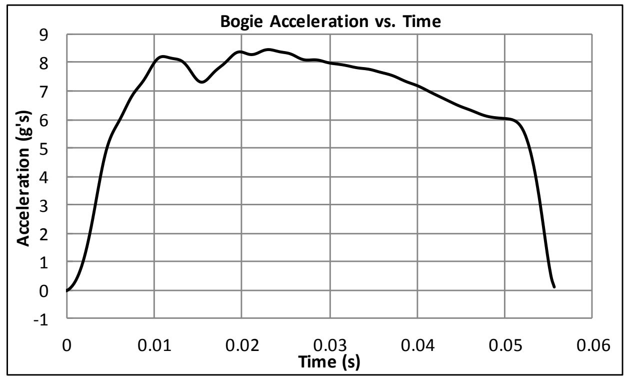
Figure C-21. Results of Test No. AZPP-5 (DTS-SLICE)

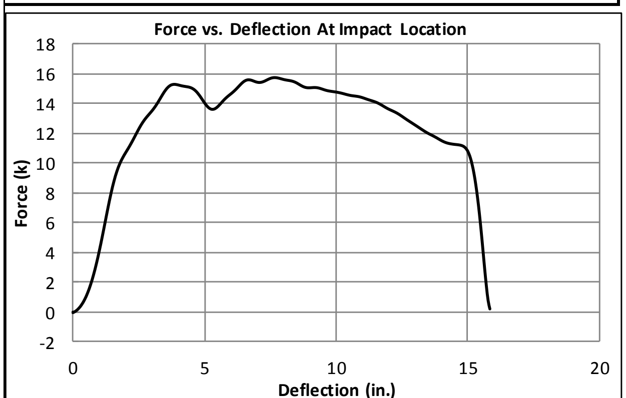
MIDWEST ROADSIDE SAFETY FACILITY

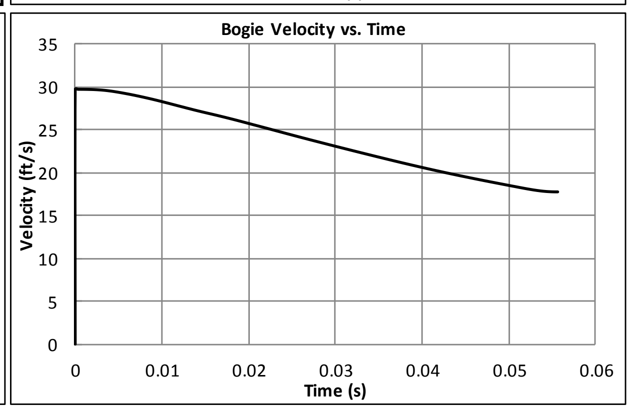
Bogie Test Summary

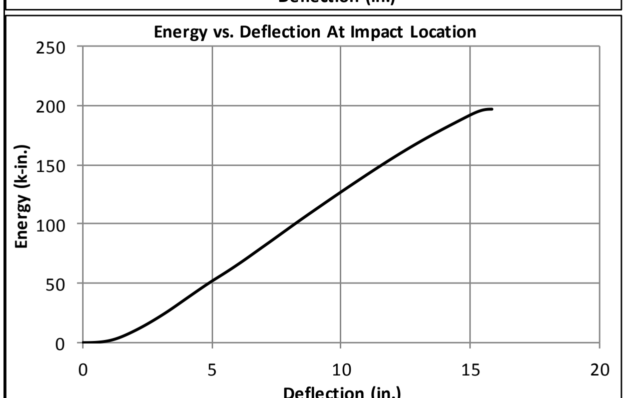
Test Information	Bogie - Post in Soil	
Test Number:	AZPP-5	
Test Date:	25-Sep-2012	
Failure Type:	Rotation Through Soil	
Post Properties		
Post Type:	Ponderosa Pine	
Post Size:	8.55" dia.	216 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.7% @ 15" - 3.5% @ 30"	
Compaction Method:	HE- 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.24 mph (29.7 fps)	9.05 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 273"	

Test Results Summary		
Max. Deflection:	15.8	in.
Peak Force:	15.7	k
Initial Linear Stiffness:	2.0	k/in.
Total Energy:	196.9	k-in.









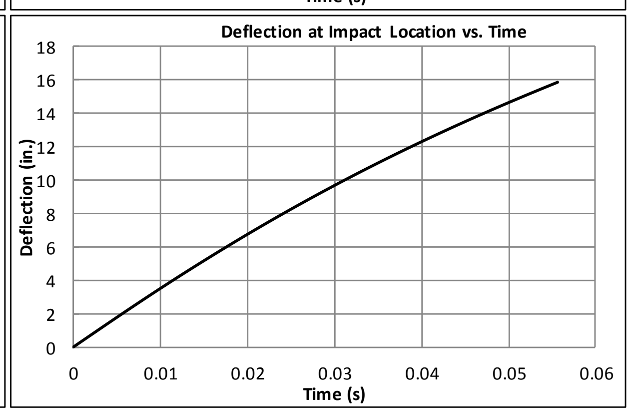


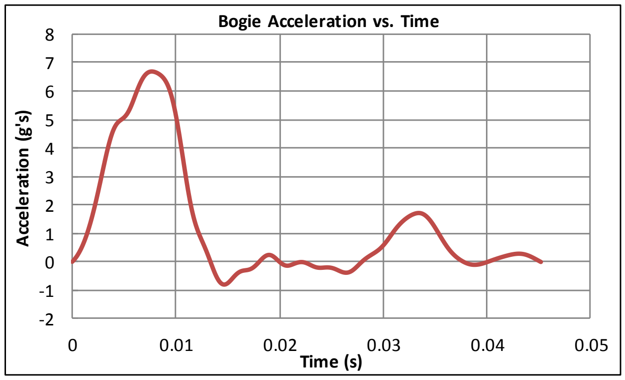
Figure C-22. Results of Test No. AZPP-5 (EDR-3)

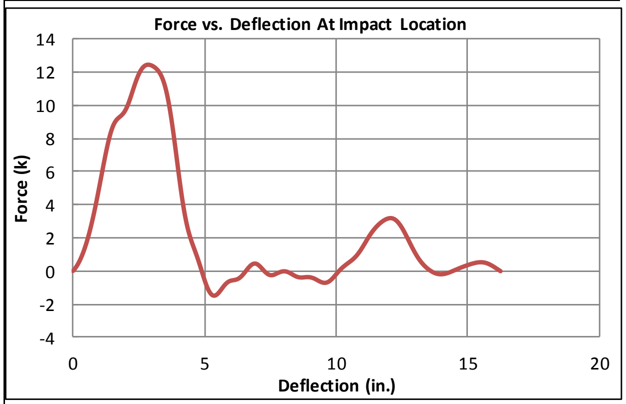
MIDWEST ROADSIDE SAFETY FACILITY

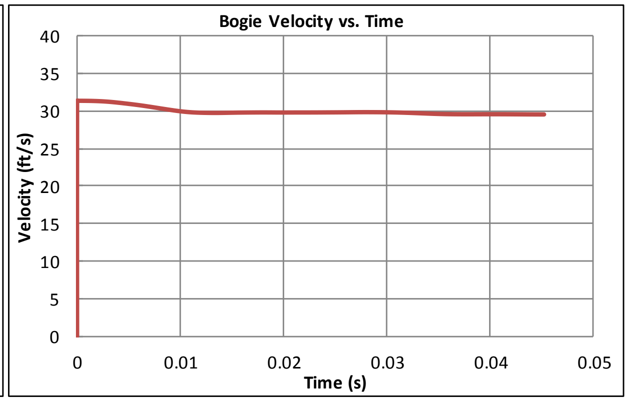
Bogie Test Summary

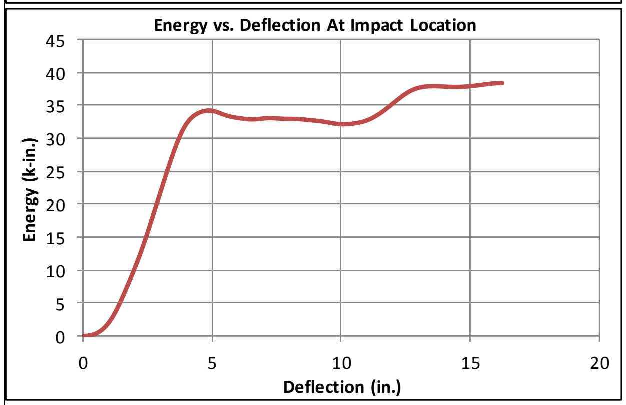
Test Information	Bogie - Post in Soil	
Test Number:	AZPP-6	
Test Date:	26-Sep-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Ponderosa Pine	
Post Size:	8.36" dia.	212 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.9% @ 15" - 3.3% @ 30"	
Compaction Method:	HE- 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.39 mph (31.4 fps)	9.56 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	SLICE	
Camera Data:	AOS-5 Perpendicular - 285"	

Test Results Summary		
Max. Deflection:	4.9	in.
Peak Force:	12.4	k
Initial Linear Stiffness:	4.3	k/in.
Total Energy:	34.2	k-in.









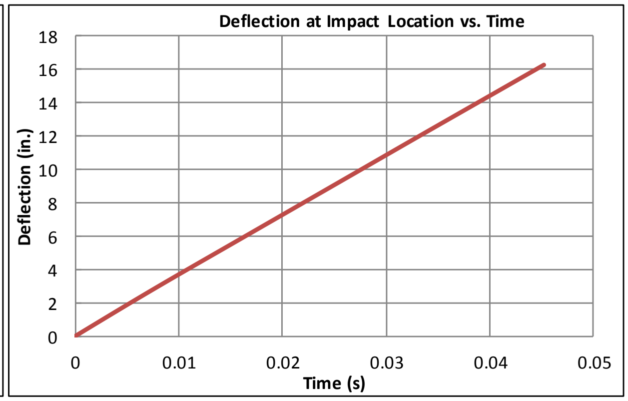


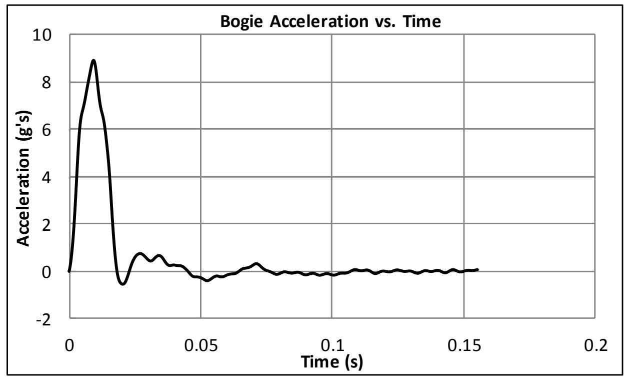
Figure C-23. Results of Test No. AZPP-6 (DTS-SLICE)

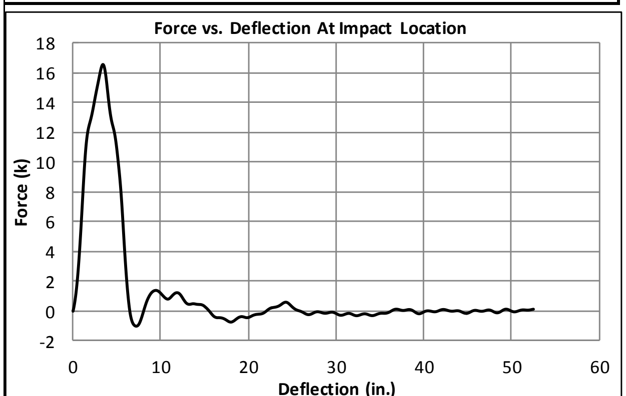
MIDWEST ROADSIDE SAFETY FACILITY

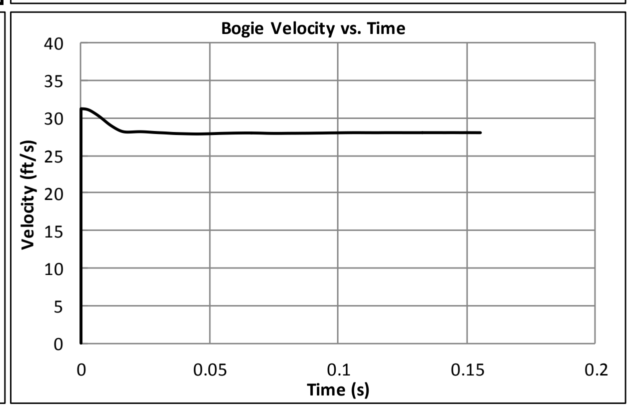
Bogie Test Summary

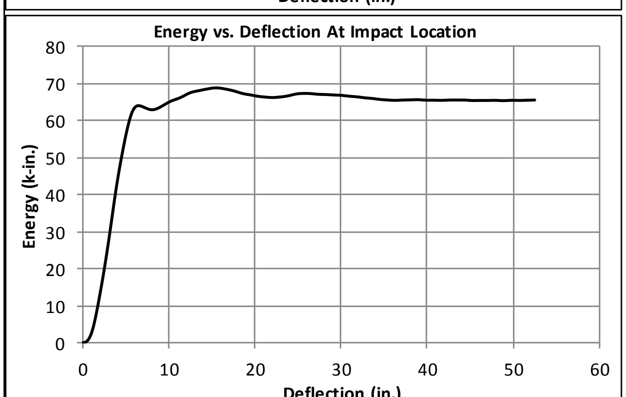
Test Information	Bogie vs. Round Wood Post	
Test Number:	AZPP-7	
Test Date:	19-Oct-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood - Ponderosa Pine	
Post Size:	8.67" dia.	220 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	40927	
Moisture Content:	NA	
Compaction Method:	H.E.-8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.3 mph (31.2 fps)	9.52 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1860 lbs	843.7 kg
Data Acquired		
Acceleration Data:	DTS SLICE	
Camera Data:	AOS-5 Perpendicular - 255"	

Test Results Summary		
Max. Deflection:	6.5	in.
Peak Force:	16.5	k
Initial Linear Stiffness:	4.8	k/in.
Total Energy:	64.0	k-in.









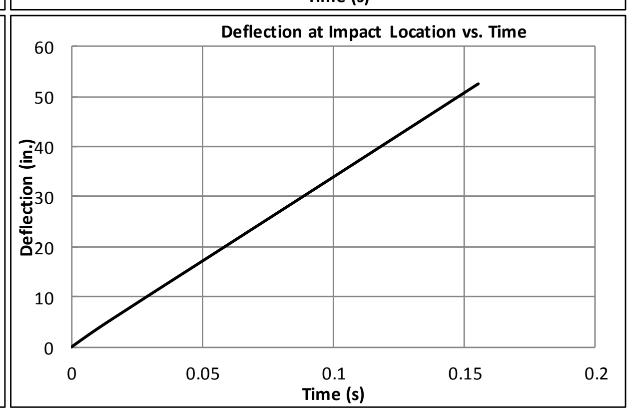


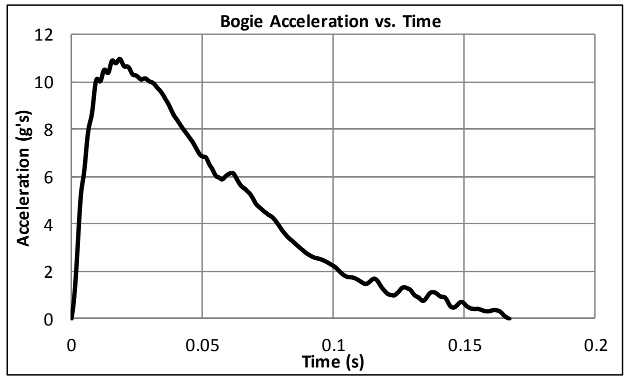
Figure C-24. Results of Test No. AZPP-7 (DTS-SLICE)

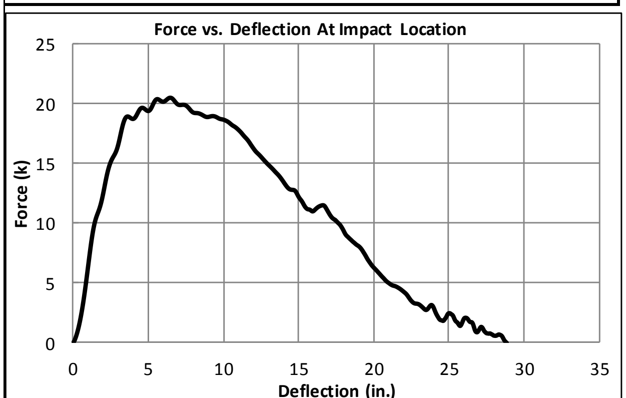
MIDWEST ROADSIDE SAFETY FACILITY

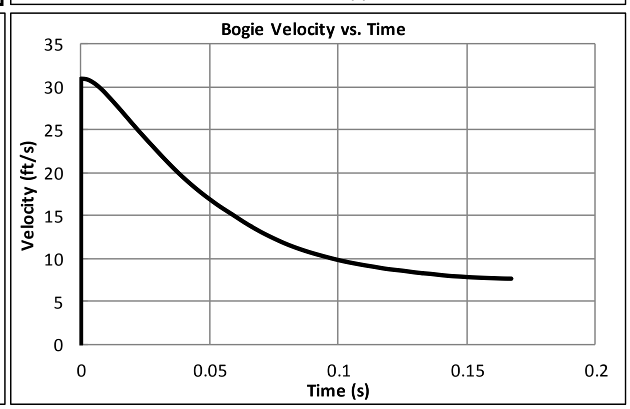
Bogie Test Summary

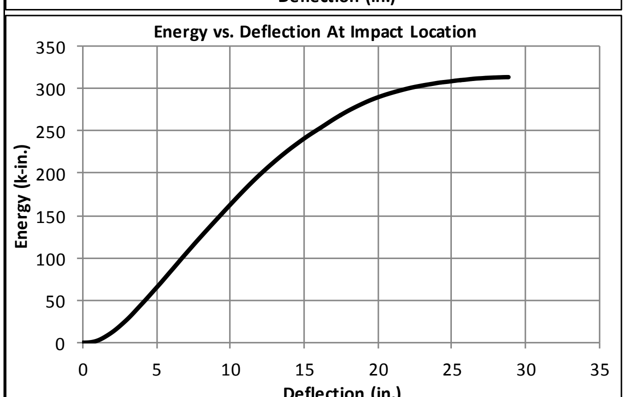
Test Information	Bogie vs. Post in Soil	
Test Number:	AZPP-8	
Test Date:	21-Nov-2012	
Failure Type:	Post Rotaion in Soil	
Post Properties		
Post Type:	Wood - Ponderosa Pine	
Post Size:	8.71" dia.	221 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.4% / 3.1%	
Compaction Method:	H.E. 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.09 mph (30.9 fps)	9.43 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1871 lbs	848.7 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-6 Perpendicular - 277"	

Test Results Summary		
Max. Deflection:	28.9	in.
Peak Force:	20.5	k
Initial Linear Stiffness:	5.5	k/in.
Total Energy:	313.5	k-in.









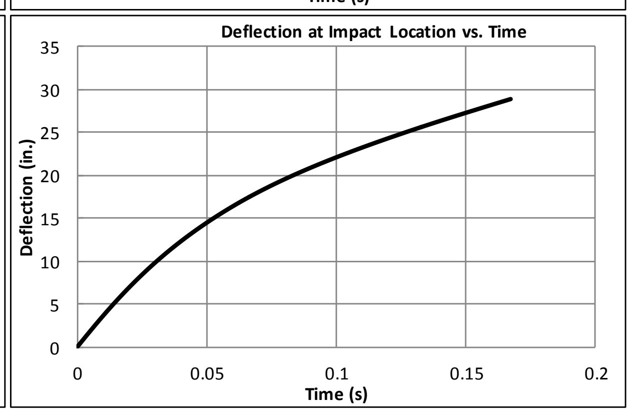


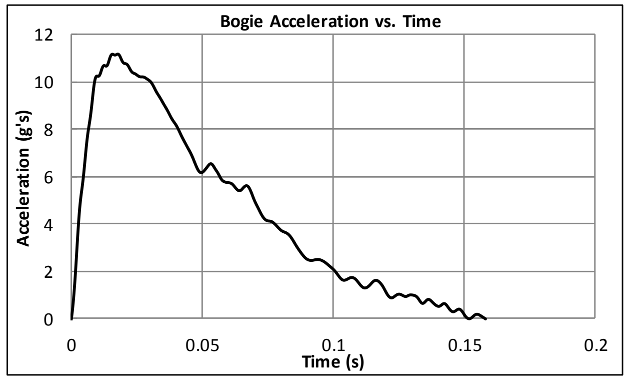
Figure C-25. Results of Test No. AZPP-8 (DTS)

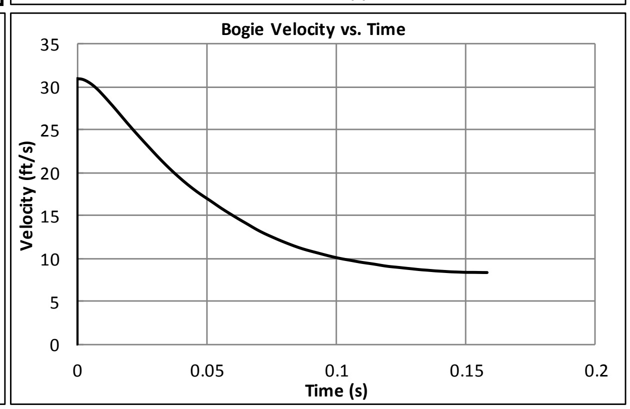
MIDWEST ROADSIDE SAFETY FACILITY

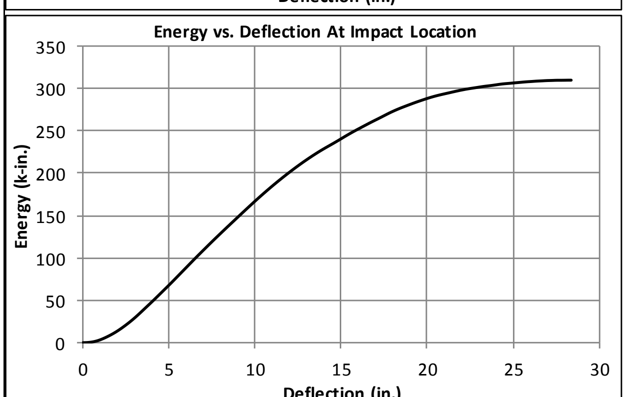
Bogie Test Summary

Test Information	Bogie vs. Post in Soil	
Test Number:	AZPP-8	
Test Date:	21-Nov-2012	
Failure Type:	Post Rotaion in Soil	
Post Properties		
Post Type:	Wood - Ponderosa Pine	
Post Size:	8.71" dia.	221 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.4% / 3.1%	
Compaction Method:	H.E. 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.09 mph (30.9 fps)	9.43 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1871 lbs	848.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-6 Perpendicular - 277"	

Test Results Summary		
Max. Deflection:	28.4	in.
Peak Force:	20.9	k
Initial Linear Stiffness:	6.2	k/in.
Total Energy:	309.9	k-in.







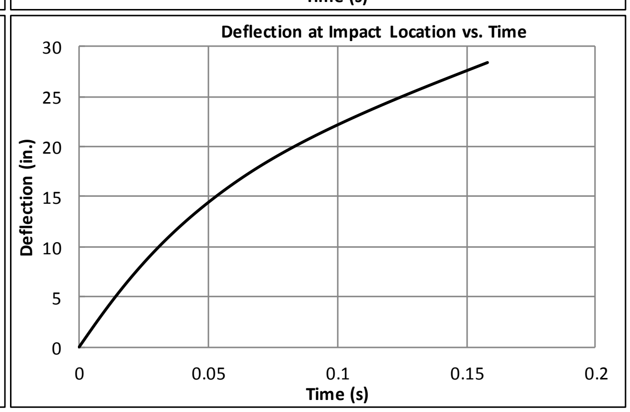


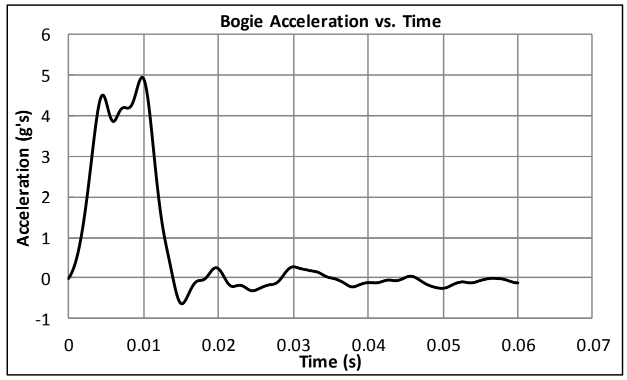
Figure C-26. Results of Test No. AZPP-8 (EDR-3)

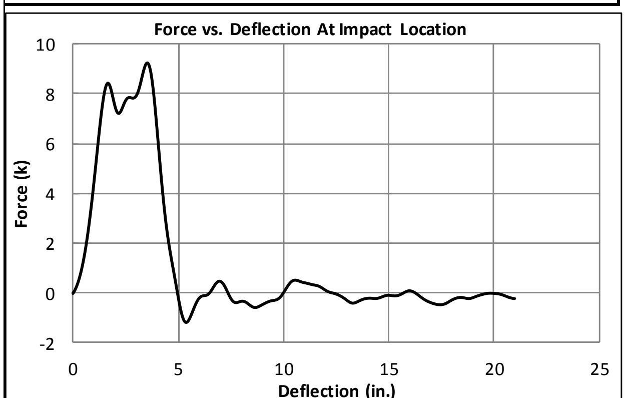
MIDWEST ROADSIDE SAFETY FACILITY

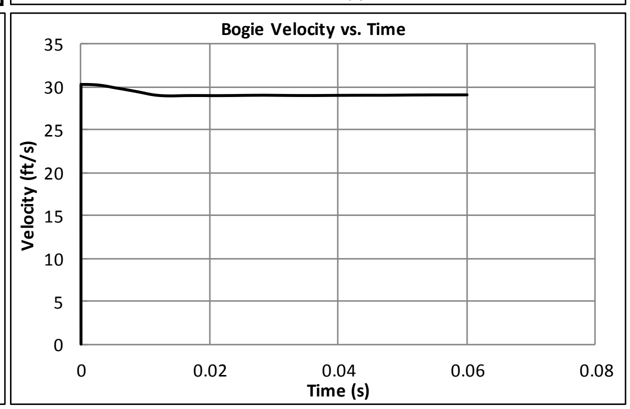
Bogie Test Summary

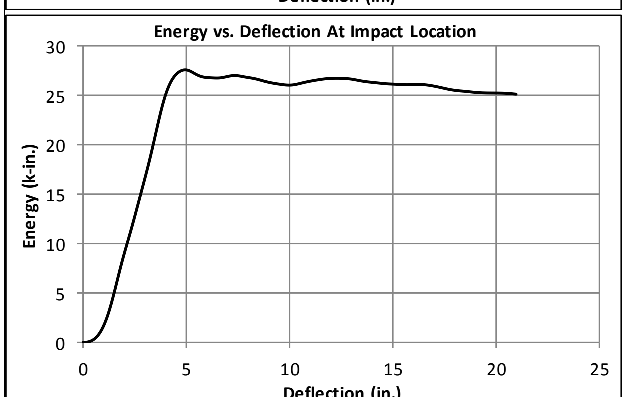
Test Information	Bogie vs. Post in Soil	
Test Number:	AZPP-9	
Test Date:	21-Nov-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood - Ponderosa Pine	
Post Size:	8.75" dia.	222 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.3% / 3.2%	
Compaction Method:	H.E. 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.65 mph (30.3 fps)	9.23 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1871 lbs	848.7 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-6 Perpendicular - 279"	

Test Results Summary		
Max. Deflection:	5.0	in.
Peak Force:	9.2	k
Initial Linear Stiffness:	5.1	k/in.
Total Energy:	27.6	k-in.









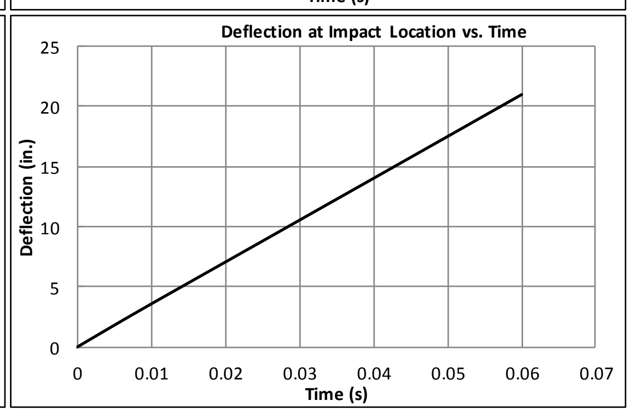


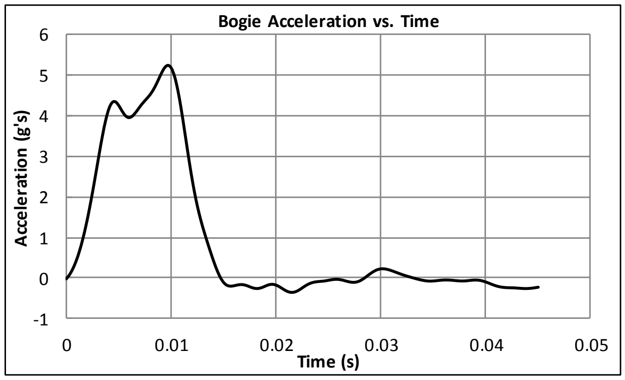
Figure C-27. Results of Test No. AZPP-9 (DTS)

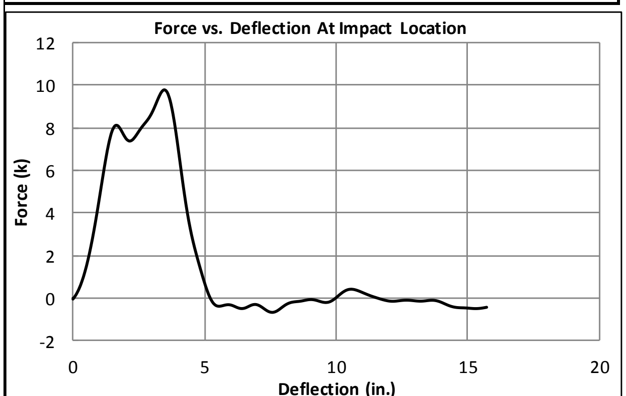
MIDWEST ROADSIDE SAFETY FACILITY

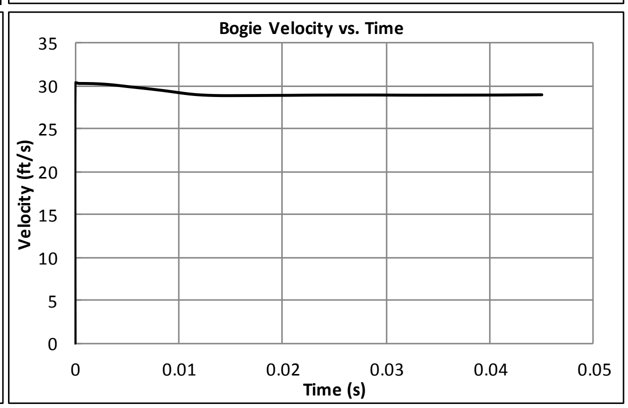
Bogie Test Summary

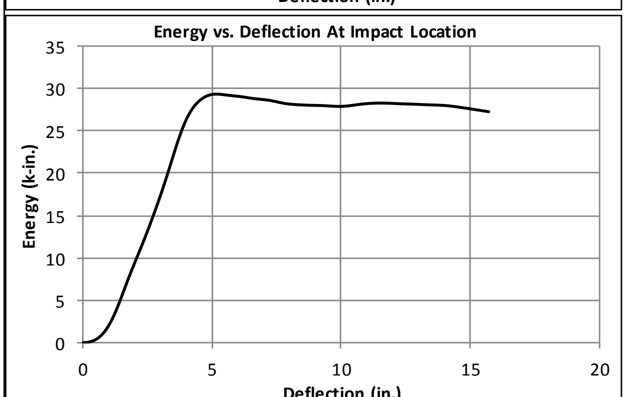
Test Information	Bogie vs. Post in Soil	
Test Number:	AZPP-9	
Test Date:	21-Nov-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood - Ponderosa Pine	
Post Size:	8.75" dia.	222 mm dia.
Post Length:	64 in.	162.6 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA	
Soil Properties		
Gradation:	1/19/2012	
Moisture Content:	3.3% / 3.2%	
Compaction Method:	H.E. 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.65 mph (30.3 fps)	9.23 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1871 lbs	848.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-6 Perpendicular - 279"	

Test Results Summary		
Max. Deflection:	5.3	in.
Peak Force:	9.8	k
Initial Linear Stiffness:	4.8	k/in.
Total Energy:	29.3	k-in.









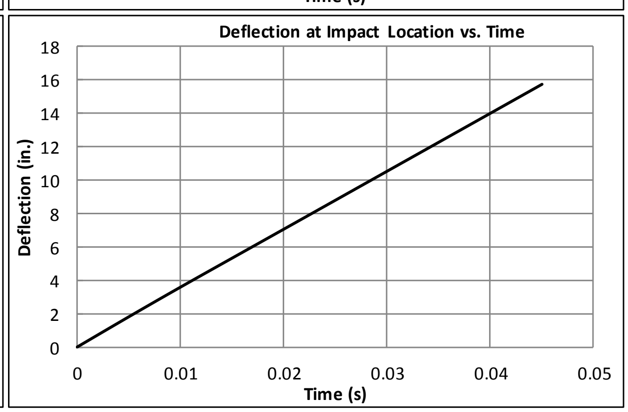


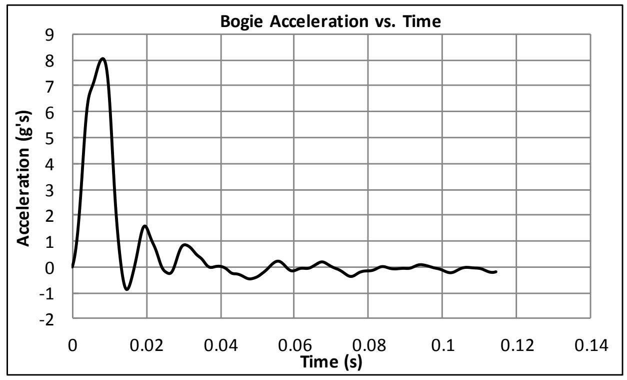
Figure C-28. Results of Test No. AZPP-9 (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Round Ponderosa Pine Post	
Test Number:	AZPP-10	
Test Date:	30-Apr-2013	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.48" dia.	215 mm dia.
Post Length:	65 in.	165.1 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA - Centered on post	
Soil Properties		
Gradation:	40927	
Moisture Content:	NA	
Compaction Method:	HE-8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	22.06 mph (32.3 fps)	9.86 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1857 lbs	842.3 kg
Data Acquired		
Acceleration Data:	DTS-SLICE	
Camera Data:	AOS-5 Perpendicular - 296"	

Test Results Summary		
Max. Deflection:	5.0	in.
Peak Force:	15.0	k
Initial Linear Stiffness:	4.8	k/in.
Total Energy:	44.6	k-in.



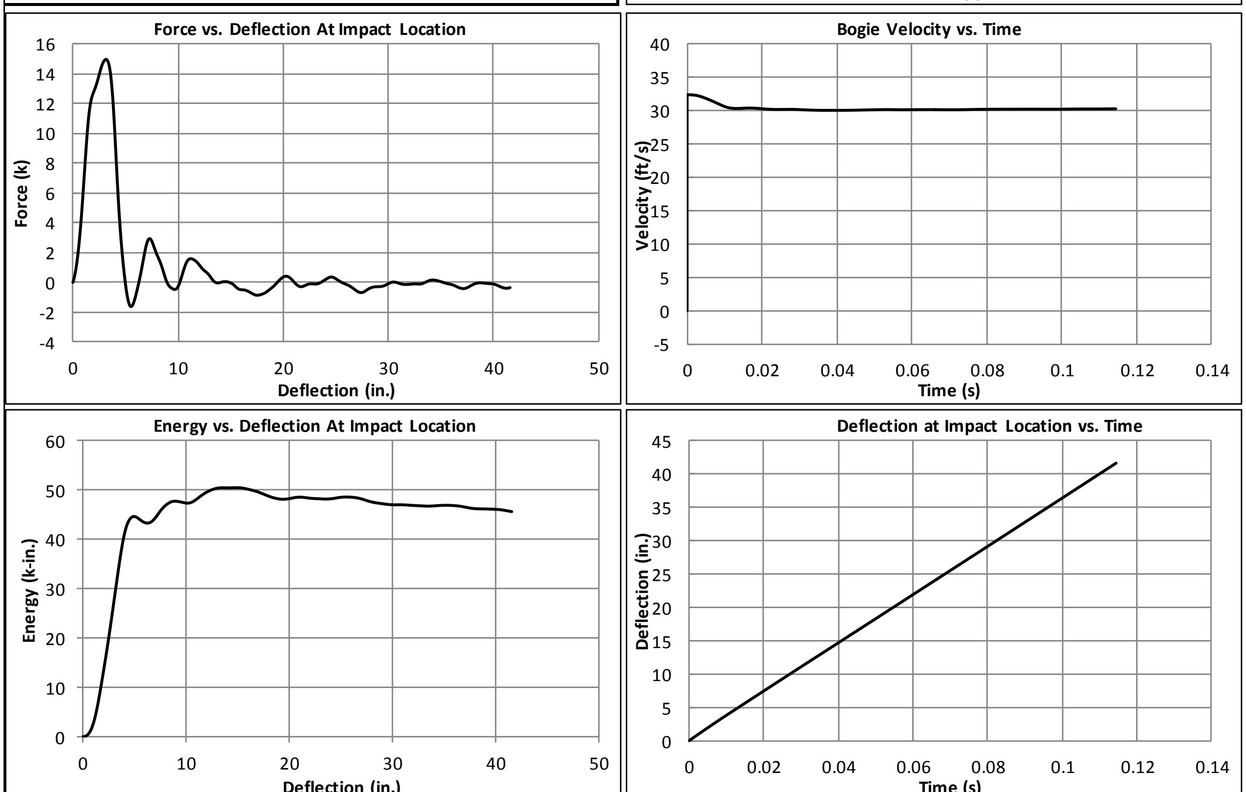


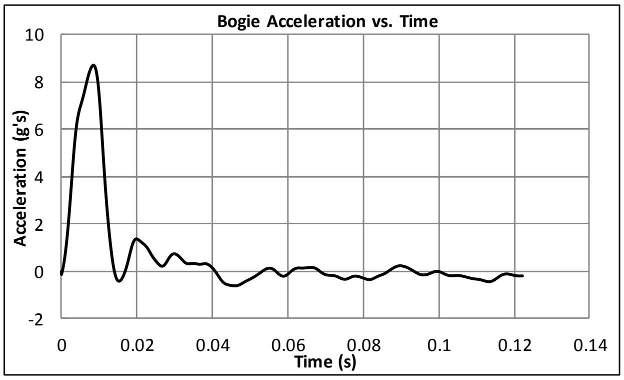
Figure C-29. Results of Test No. AZPP-10 (DTS-SLICE)

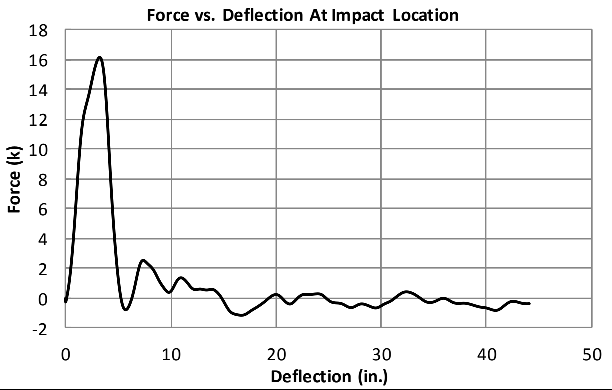
MIDWEST ROADSIDE SAFETY FACILITY

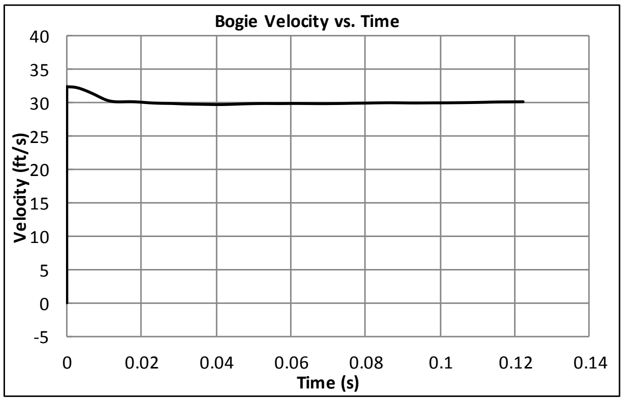
Bogie Test Summary

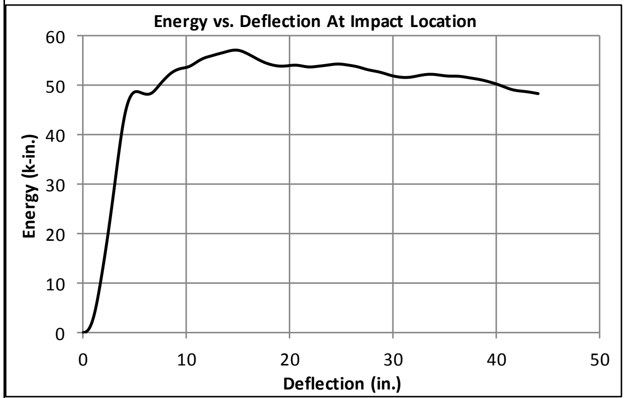
Test Information	Round Ponderosa Pine Post	
Test Number:	AZPP-10	
Test Date:	30-Apr-2012	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.48" dia.	215 mm dia.
Post Length:	65 in.	165.1 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA - Centered on post	
Soil Properties		
Gradation:	40927	
Moisture Content:	NA	
Compaction Method:	HE-8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	22.06 mph (32.3 fps)	9.86 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1857 lbs	842.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 296"	

Test Results Summary		
Max. Deflection:	5.3	in.
Peak Force:	16.1	k
Initial Linear Stiffness:	5.0	k/in.
Total Energy:	48.7	k-in.









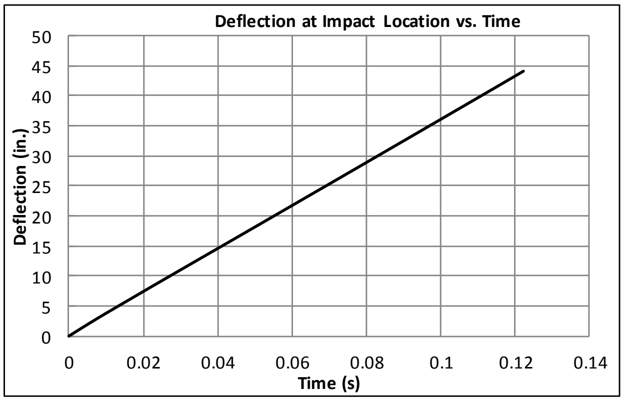


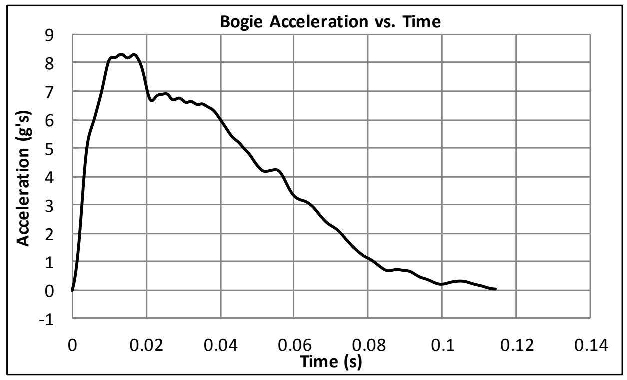
Figure C-30. Results of Test No. AZPP-10 (EDR-3)

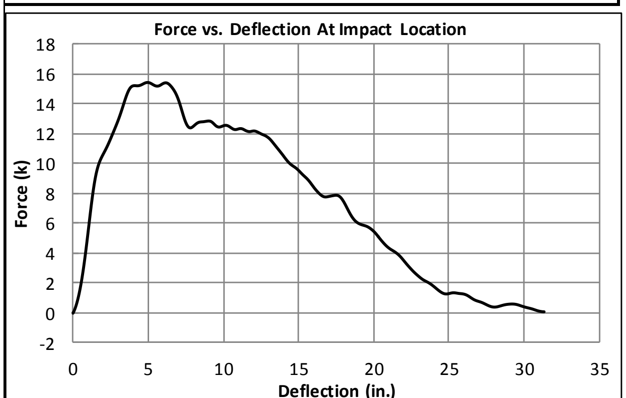
MIDWEST ROADSIDE SAFETY FACILITY

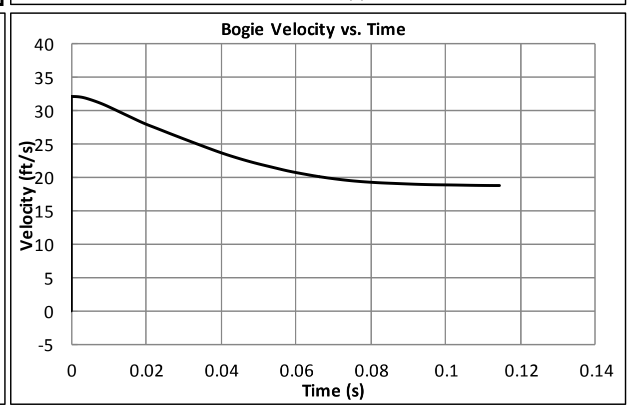
Bogie Test Summary

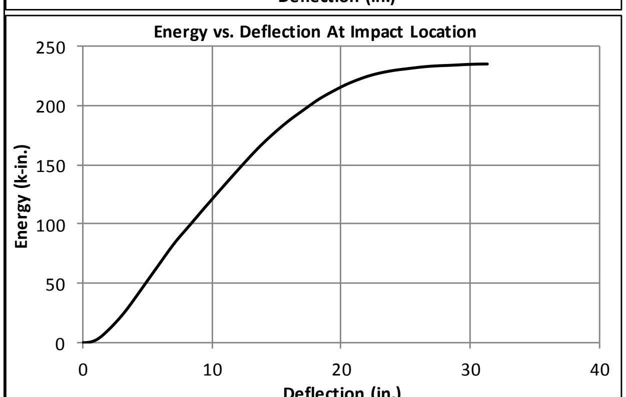
Test Information	Round Ponderosa Pine Post	
Test Number:	AZPP-11	
Test Date:	30-Apr-2013	
Failure Type:	Rotation Through Soil	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.44" dia.	214 mm dia.
Post Length:	65 in.	165.1 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA - Centered on post	
Soil Properties		
Gradation:	40927	
Moisture Content:	NA	
Compaction Method:	HE-8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.9 mph (32.1 fps)	9.79 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1857 lbs	842.3 kg
Data Acquired		
Acceleration Data:	DTS-SLICE	
Camera Data:	AOS-5 Perpendicular - 296"	

Test Results Summary		
Max. Deflection:	31.3	in.
Peak Force:	15.4	k
Initial Linear Stiffness:	4.0	k/in.
Total Energy:	235.0	k-in.









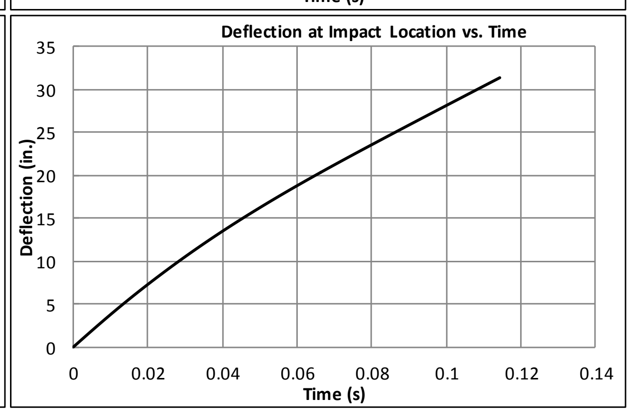


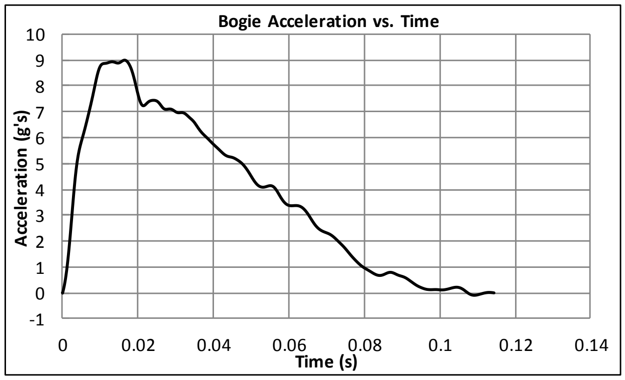
Figure C-31. Results of Test No. AZPP-11 (DTS-SLICE)

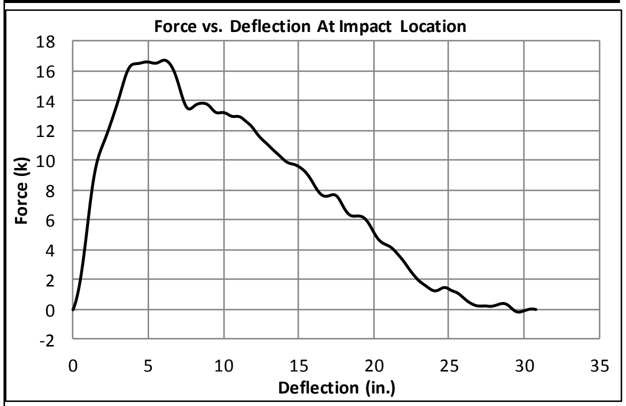
MIDWEST ROADSIDE SAFETY FACILITY

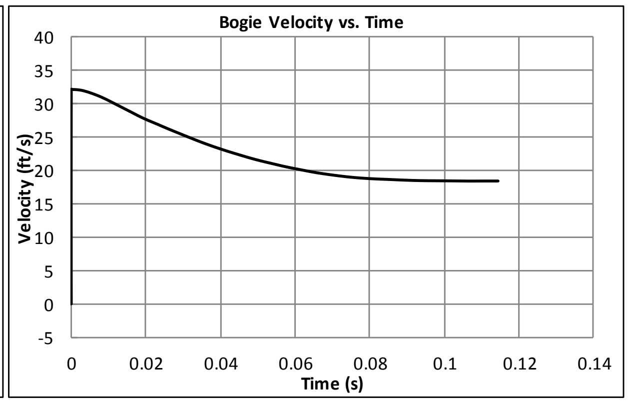
Bogie Test Summary

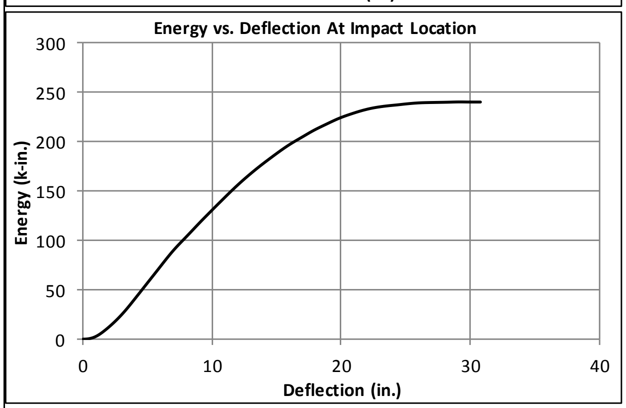
Test Information	Round Ponderosa Pine Post	
Test Number:	AZPP-11	
Test Date:	30-Apr-2012	
Failure Type:	Rotation Through Soil	
Post Properties		
Post Type:	Round Ponderosa Pine	
Post Size:	8.44" dia.	214 mm dia.
Post Length:	65 in.	165.1 cm
Embedment Depth:	35 in.	88.9 cm
Orientation:	NA - Centered on post	
Soil Properties		
Gradation:	40927	
Moisture Content:	NA	
Compaction Method:	HE-8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	21.9 mph (32.1 fps)	9.79 m/s
Impact Height:	21.625 in.	54.9 cm
Bogie Mass:	1857 lbs	842.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 296"	

Test Results Summary		
Max. Deflection:	30.8	in.
Peak Force:	16.7	k
Initial Linear Stiffness:	4.4	k/in.
Total Energy:	240.1	k-in.









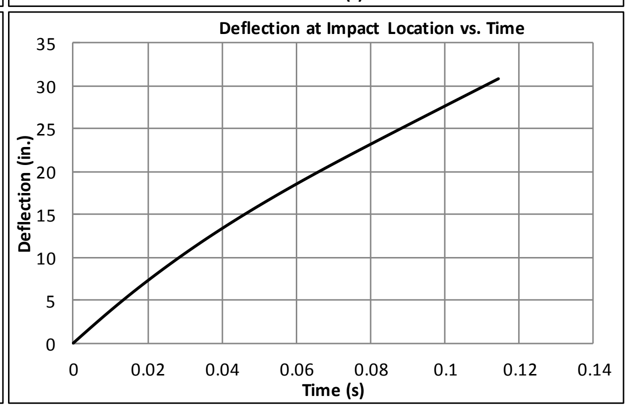


Figure C-32. Results of Test No. AZPP-11 (EDR-3)

Appendix D. FPL Post Inspection and Examination of Fractured Posts

M E M O R A N D U M

To: The Record
Cc: Ron Faller, Randy Nicoll, Bill Greenwood, Mike Ritter

From: David E. Kretschmann
Research Engineer
Phone: 608-231-9307
Fax: 608-231-9303

Subject: Trip report memo for visit to University of Nebraska-Lincoln
Date: January 27, 2013

In a conference call on December 20th 2012 it was agreed that Ron Faller from University of Nebraska-Lincoln and Randy Nicoll from Arizona Log and Timberworks and I would meet would at the MwRSF on January 25th, to examine the failure surfaces of the posts tested by MwRSF for clues as to why the material failed a load below what was expected. Bill Greenwood, Executive Director of Northern Arizona Wood Products Association also made the trip from Arizona. This memo documents my January 25th, 2013 visit to the Midwest Roadside Safety Facility (MwRSF).

The guardrail post testing was conducted to establish diameter and embedment depth for round post as substitutes for rectangular posts in the current AzDOT guardrail systems. These posts are meant to provide an alternate post type for the current guard rail system used by the AzDOT as well as provide an alternate for replacement when the current systems are damaged until AzDOT adopts the new Midwest guardrail system. The results of the testing is summarized in Table 11 below. There were three different sets of three round posts. In each of these three cases two of the three posts failed in fracture rather than rotating as expected. In one case (AZPP-9 the largest post had the lowest load of any test).

After a close examination of the posts it appears that much of the curious results observed in the testing were a result of grading issues (slope of grain, ring shake, and decayed heart that could have suggested by bark inclusions) with the posts (Table 1). I have included the photos I took as documentation of the issues. In four of the six post there were clearly grading problems.

Table 1-Notes on Grading of posts

Test No.	Grading issue
AZPP-1	Ring Shake was present. Also there were a large juvenile wood core
AZPP-3	Ring Shake present and some slope of grain
AZPP-4	Big juvenile wood core off centered
AZPP-6	Severe Slope of grain
AZPP-7	Large juvenile wood core with severely off-centered core
AZPP-9	Decayed heart as indicated by substantial wound and large bark inclusion

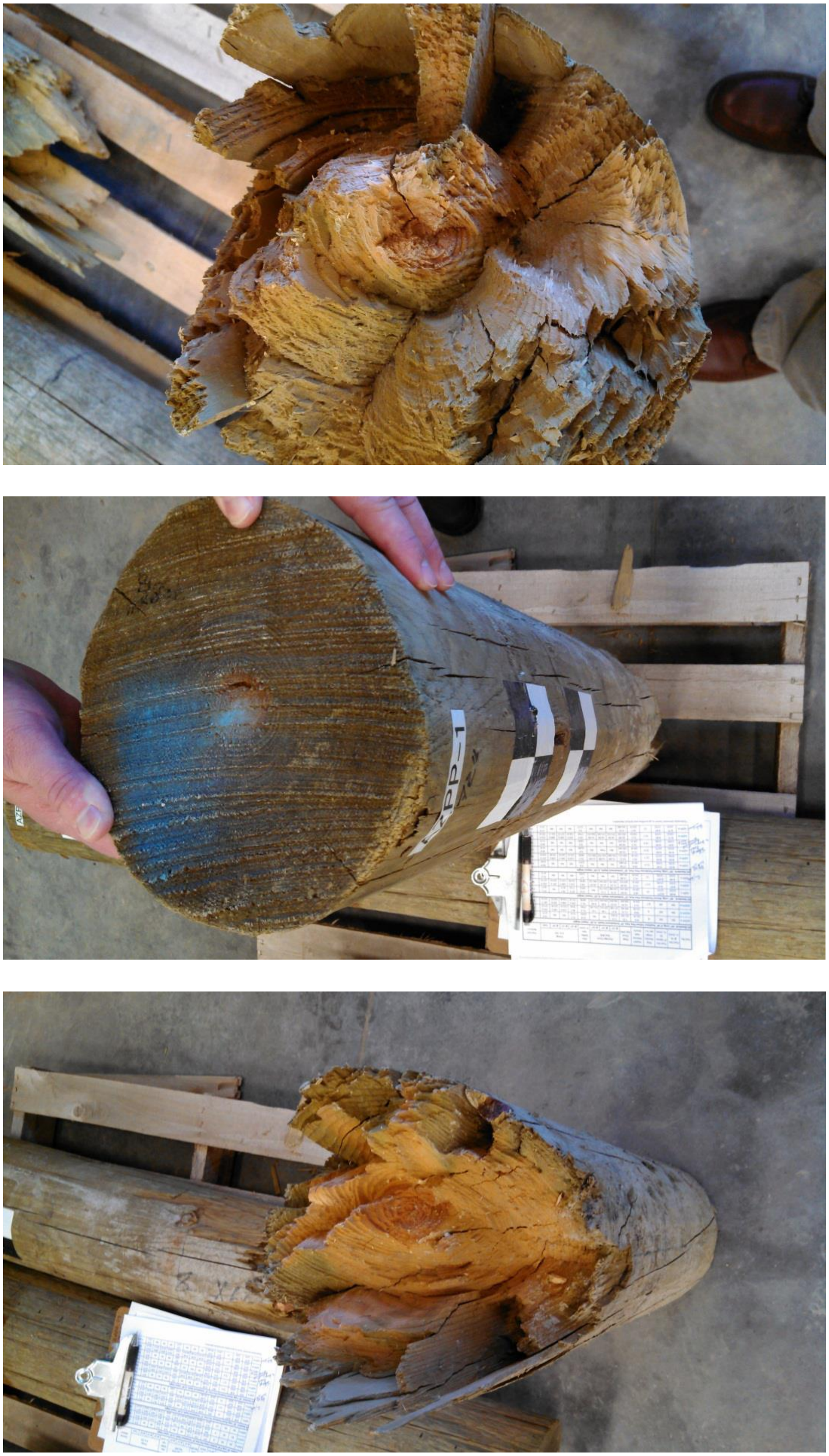


Figure AZPP-1: Ring Shake and Large Juvenile Wood Core.

Figure AZPP-3: Ring Shake and some Slope of Grain Concern

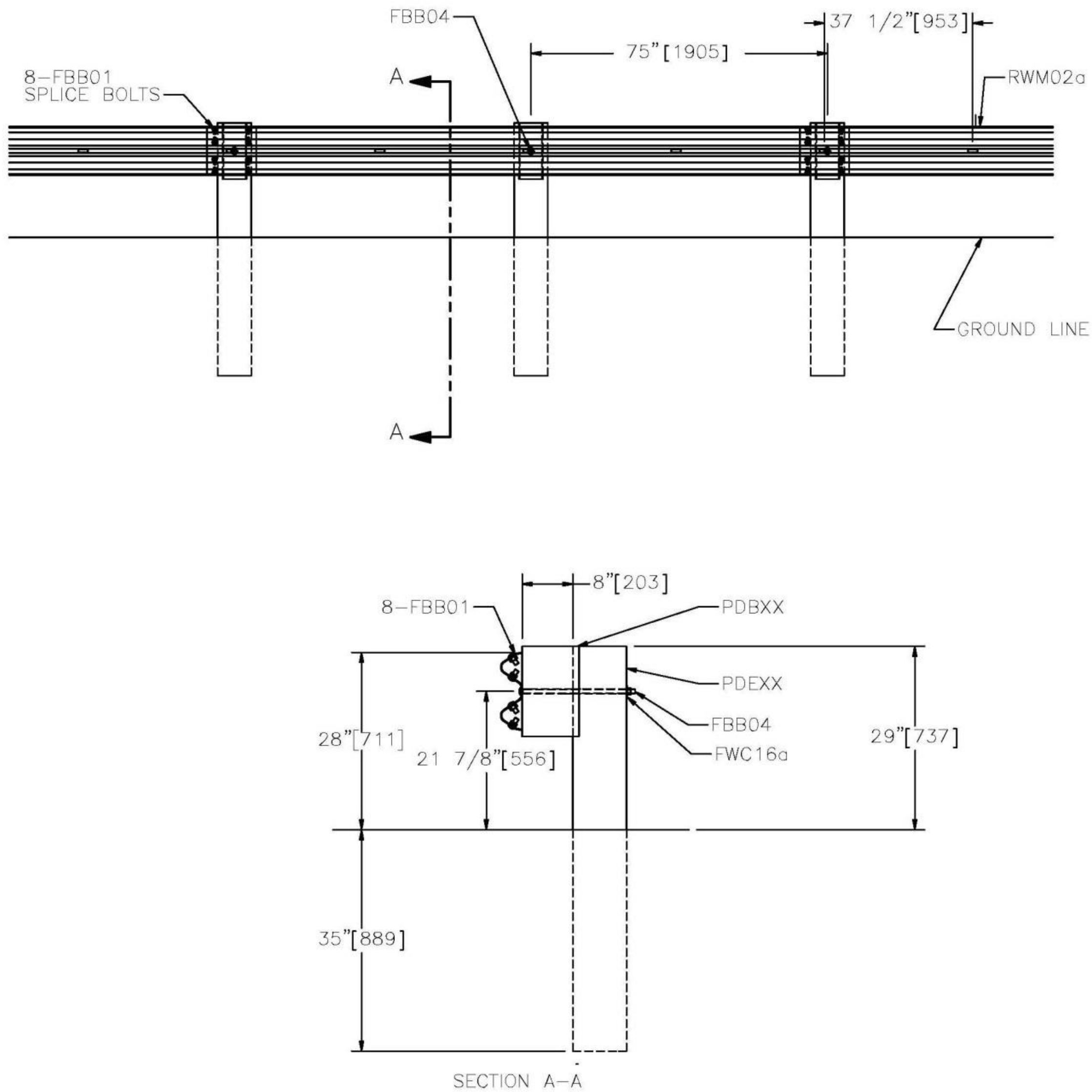
Figure AZPP-4: Large Core and Off-Centered Pith

Figure AZPP-6: Substantial Slope of grain present in the posts.

AZPP-7: Large juvenile wood core and very off-centered heart as well.

Figure AZPP-9: Wound with large amount of bark present also clear indications of a decayed core.

Appendix E. Design Details of G4(2W) Guardrail System for Use with Round Posts



POST	BLOCKOUT OPTION
	SINGLE
PDEXX	PDBXX

G4(2W) GUARDRAIL SYSTEM FOR USE WITH ROUND POSTS

SGRXX

SHEET NO.	DATE:
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Figure E-1. G4(2W) Guardrail System for Use with Round Posts, Sheet 1

INTENDED USE

G4(2W) guardrail system with Ponderosa Pine (PP) (PDEXX) Round Posts and standard post spacing (SGRXX) should be anchored and terminated using a suitable guardrail end treatment that is approved for a 28" [711] top mounting height. The timber blockout may be the same timber species as those furnished for the wood posts, but is not required. G4(2W) guardrail system with Round Posts should meet the TL-3 NCHRP 350 safety performance criteria.

COMPONENTS

Unit Length 12'-6" [3810]

DESIGNATOR	COMPONENT	NUMBER
FBB01	Guardrail splice bolts and nuts	8
FBB04	Guardrail post bolts and nuts	2
FWC16a	Round Washer	2
PDBXX	Routered Timber Blockout	2
PDEXX	Round Wood Post	2
RMW02a	W-Beam Rail	1

CONTACT INFORMATION

Midwest Roadside Safety Facility
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, NE 68583-0853
(402) 472-0965
Email: mwrsf@unl.edu
Website: http://mwrsf.unl.edu/

G4(2W) GUARDRAIL SYSTEM FOR USE WITH ROUND POSTS

SGRXX	
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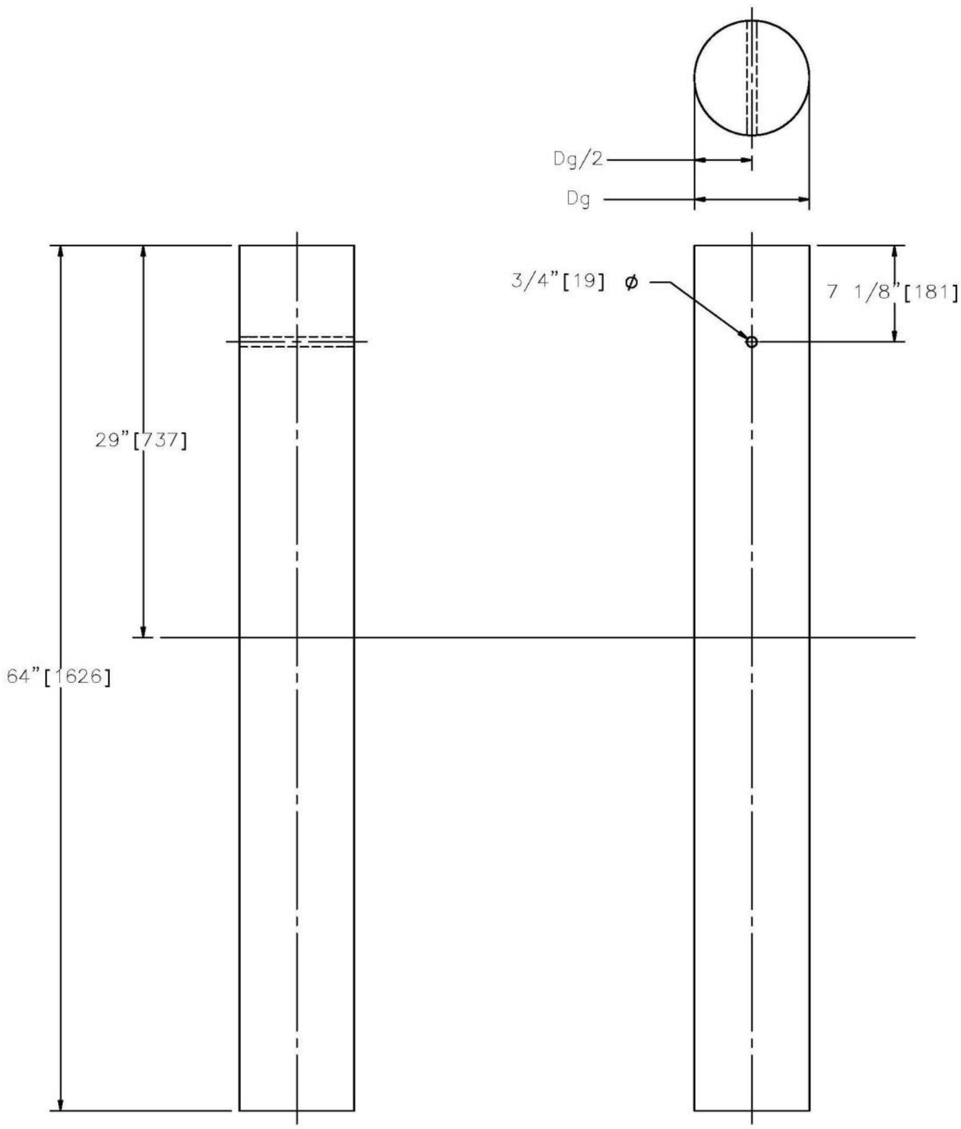
Figure E-2. G4(2W) Guardrail System for Use with Round Posts, Sheet 2

Designator	Wood Type	Ground Line Diameter, Dg
PDEXX	Ponderosa Pine	8 1/2" [216]



ROUND POST FOR G4(2W) GUARDRAIL SYSTEM

PDEXX

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Figure E-3. Round Post for G4(2W) Guardrail System, Sheet 1

SPECIFICATIONS

The Ponderosa Pine (PP) round post (PDEXX) is for use in G4(2W) W–beam guardrail systems and shall be manufactured of material that conforms to the guidelines shown below.

General:

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 8½" [216] diameter guardrail posts will be a minimum of 64" [1626] 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 35" [889] from the butt end of each post.

Size:

The size of the Ponderosa Pine posts shall be classified based on their diameter at the ground line and their length. The ground line diameter shall be specified by diameter in ¼" [6] breaks. The length shall be specified in 12" [300] 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 3" [75] longer. The diameter of the Ponderosa Pine post shall be 8½" [216] diameter at the ground line with an upper limit of 9" [229].

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" [25].

Shape and Straightness:

All Ponderosa Pine 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 1¼" [32] at any point. Posts shall be free from reverse bends.

ROUND POST FOR G4(2W) GUARDRAIL SYSTEM

PDEXX	
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Figure E-4. Round Post for G4(2W) Guardrail System, Sheet 2

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.

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3.5" [89] or smaller.

Decay:
Allowed in knots only.

Holes:
Pin holes 1/16" [1] or less are not restricted.

Slope of Grain:
1 in 10.

Compression Wood:
Not allowed in the outer 1" [25] or if exceeding one-quarter of the radius.

Ring Density:
Ring density shall be at least 6 rings-per-inch, as measured over a 3" [76] length.

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 treated post shall have a minimum sapwood depth of ¾" [19], 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.

ROUND POST FOR G4(2W) GUARDRAIL SYSTEM

MwRSF	PDEXX	
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Figure E-5. Round Post for G4(2W) Guardrail System, Sheet 3

The posts shall have cross-sectional properties as shown below:

Post Material	Ground Line Diameter, Dg in. [mm]	Area in.^{2} [10^3mm^2]	I_x in.^{4} [10^6mm^4]	I_y in.^{4} [10^6mm^4]	S_x in.^{3} [10^3mm^3]	S_y in.^{3} [10^3mm^3]
Ponderosa Pine	8½ [216]	56.7 [36.6]	256.2 [106.7]	256.2 [106.7]	60.3 [988]	60.3 [988]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

This Ponderosa Pine round post may be used in the G4(2W) Guardrail System (SGRXX). The PDBXX timber blockout is for use with the round post (PDEXX) and is attached to the RMW02a guardrail using a FBB04 guardrail bolt and nut.

CONTACT INFORMATION

Midwest Roadside Safety Facility
University of Nebraska–Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, NE 68583–0853
(402) 472–0965
Email: mwrsf@unl.edu
Website: http://mwrsf.unl.edu/

ROUND POST FOR G4(2W) GUARDRAIL SYSTEM

PDEXX

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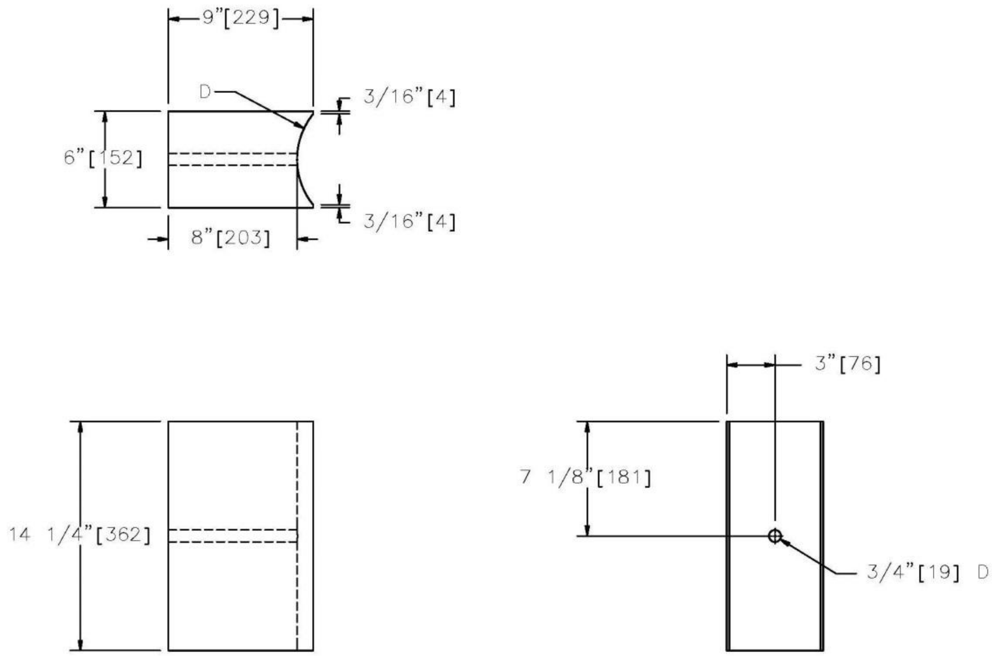
Figure E-6. Round Post for G4(2W) Guardrail System, Sheet 4

Designator	Route Diameter, D	Wood Blockout Type
PDBXX	9" [229]	Ponderosa Pine



BLOCKOUTS FOR G4(2W) ROUND POST APPLICATIONS

PDBXX	
SHEET NO.	DATE:
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Figure E-7. Blockouts for G4(2W) Round Post Applications, Sheet 1

SPECIFICATIONS

Blockouts shall be made of timber with a stress grade of at least 1,160 psi [8 MPA]. Grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other timber association. Timber for blockouts shall be either rough sawn (un-planed) or S4S (surface 4 sides) with nominal dimensions as indicated. The variation in size of the blockout in the direction parallel with the axis of the bolt shall not be more than 1/4" [6]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M-133 after all end cuts are made and holes are drilled.

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

The blockouts shall conform to the following regulations:

Component	Wood Type	Height	Depth	Width	Route Diameter, D
PDBXX	Ponderosa Pine	14¼" [362]	9" [229]	6" [152]	9" [229]

INTENTED USE

This blockout is used with round wood post (PDEXX) in G4(2W) guardrail systems along with Round Post variations (SGRXX).

CONTACT INFORMATION

Midwest Roadside Safety Facility
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, NE 68583-0853
(402) 472-0965
Email: mwrsf@unl.edu
Website: http://mwrsf.unl.edu/

BLOCKOUTS FOR G4(2W) ROUND POST APPLICATIONS

PDBXX	
SHEET NO.	DATE:
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Figure E-8. Blockouts for G4(2W) Round Post Applications, Sheet 2

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