PHASE II PONDEROSA PINE ROUND POST EQUIVALENCY STUDY

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16. Abstract (Limit: 200 words)

The research objective was to determine the appropriate size and embedment depth of a round Ponderosa Pine (PP) post for use as a surrogate for the standard 6-in. x 8-in. x 72-in. (152-mm x 203-mm x 1,829-mm) Southern Yellow Pine (SYP) post used in G4(2W) guardrail systems. Nine dynamic component tests were conducted on the standard rectangular SYP posts and round PP posts in two separate rounds. Round 1 of testing was conducted in strong soil and evaluated the posts' ultimate strengths. Results indicated that a minimum diameter of 8⅝ in. (219 mm) should be used for PP posts to replicate the SYP post strength. Round 2 of testing was conducted within a moderately compacted soil and evaluated the soil resistance of each post. An embedment depth of 36 in. (914 mm) was found to provide equivalent soil resistance to the rectangular SYP post. Based on these test results, an 8⅝-in. (219-mm) diameter PP post with a 36-in. (914-mm) embedment depth was recommended as the surrogate post for the SYP post utilized in most U.S. standard G4(2W) guardrail systems.

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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, Ph.D., E.I.T., Post-Doctoral Research Associate.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

Over the last several decades, the southwestern United States 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 focused on 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, 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]. In response to this need, researchers at the Midwest Roadside Safety Facility (MwRSF), in cooperation with the Forest Products Laboratory (FPL) and the USDA - Forest Service, developed an adaptation of the Midwest Guardrail System (MGS) that utilized SDT materials as timber posts [5]. The study determined appropriate sizes of Southern

Yellow Pine (SYP), Douglas Fir (DF), and Ponderosa Pine (PP) round posts for use within the 31-in. (787-mm) tall corrugated W-beam system.

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 guardrail systems. Two additional W-beam guardrail systems were identified as systems that may be compatible with PP posts: the U.S. standard G4(2W) guardrail system and the Arizona DOT W-beam guardrail system. Although these guardrail systems utilize similar components to the wood post version of the MGS, differences in rail height and embedment depth exist between the three systems, as shown in Table 1. As a result, there may be in different post performance requirements for each system. Therefore, further research was undertaken in a combined effort between MwRSF, the USDA-Forest Service, and FPL to determine the appropriate dimensions (diameter and length) and embedment depth of round PP posts for use within these two W-beam guardrail systems.

Phase I of this PP equivalency study incorporated 17 dynamic component tests on various wood posts, 6 of these on rectangular SYP posts and 11 on round PP posts with diameters between 8⅜ in. and 8¾ in. (213 mm and 222 mm). Based on the results of these component tests, an 8½-in. (216-mm) diameter PP post with a 35-in. (889-mm) embedment depth was found to provide strength and soil rotation resistance equivalent to the rectangular SYP post embedded 35 in. (889 mm) [6]. Subsequently, this equivalent round PP post was recommended for use as a surrogate post for use in the Arizona guardrail system, as noted within Table 1. However, an equivalent round PP post had yet to be determined for use in the U.S. standard G4(2W) guardrail system.

Table 1. Wood Post Options for W-beam Guardrail Systems

System	Top Rail Height in. (mm)	Rectangular SYP Post Option			Round PP Post Option		
		Cross Section in. (mm)	Length in. (mm)	Embedment Depth in. (mm)	Diameter in. (mm)	Length in. (mm)	Embedment Depth in. (mm)
MGS	31 (787)	6 x 8 (152 x 203)	72 (1,829)	40 (1,016)	8 (203)	69 (1,753)	37 (940)
Arizona System	28 (711)	6 x 8 (152 x 203)	64 (1,626)	35 (889)	8½ (216)	64 (1,626)	35 (889)
U.S. System G4(2W)	27¾ (705)	6 x 8 (152 x 203)	72 (1,829)	43¼ (1,099)			

Determined during Phase I of project
To be determined in this Phase II project

1.2 Objective

The objective for this project was to determine the appropriate size and embedment depth for round PP posts to serve as a surrogate for the 6-in. x 8-in. (152-mm x 203-mm) SYP posts used in the U.S. standard G4(2W) guardrail system. This component testing equivalency study 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 [7]. 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. Initially, preliminary PP post dimensions were determined based on the results obtained from Phase I of the project. Next, a total of nine dynamic component tests were conducted on rectangular SYP and round PP posts over two rounds of testing. The first round of testing was conducted in a stiff, strong soil to compare the strength of the two post alternatives, while round two of testing was conducted in a moderately compacted soil to compare the soil resistive forces. 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 used within the U.S. standard G4(2W) guardrail system.

2 COMPONENT TESTING CONDITIONS

2.1 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 city campus.

2.2 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.

2.2.1 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 8-in. (203-mm) 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 impact head and accelerometers, varied throughout the testing program, but remained between 1,633 lb and 1,928 lb (741 kg and 875 kg).

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-control braking system was installed on the bogie, allowing it to be brought safely to rest after the test.

Figure 1. Rigid-Frame Bogie Vehicle

2.2.2 Accelerometers

A combination of four different 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 specific accelerometers utilized during each component test are shown in Table 2.

Table 2. Accelerometers Utilized During Each Component Test

Test No.	SLICE-1	SLICE-2	DTS	EDR-3
SYPUS-1			X	X
SYPUS-2	X		X	X
PPUS-1		X		
PPUS-2		X		
PPUS-3		X		
PPW-1		X		
PPW-2		X		
PPSYPW-1		X		
PPSYPW-2		X		

The first two systems, the SLICE-1 and SLICE-2 units, were nearly identical modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal

Beach, California. The acceleration sensors were mounted inside the bodies of custom-built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessors. Each 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 program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The third accelerometer system, the DTS unit, was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. 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. 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 eight 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 fourth system, the EDR-3, was a triaxial piezoresistive accelerometer system manufactured by Instrumented Sensor Technology, Inc. (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.

2.2.3 Retroflective Optic Speed Trap

The 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 vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box, activating the LED flashes. 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.

2.2.4 Photography Cameras

One AOS high-speed digital video camera, one JVC digital video camera and one GoPro Hero 3 digital video camera were used to document each test. The AOS, the JVC, and the GoPro 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.

2.3 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 farther 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 either of the following events was used to determine the end of the test: (1) the test article fractures or (2) the surrogate vehicle overrides/loses contact with the test article.

2.4 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 [8]. 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. The initial velocity of the bogie, calculated from the optic speed trap data, was then used to determine the bogie's 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 versus deflection curve for 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 by 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 the 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 to obtain acceleration, velocity, and deflection curves, as well as force versus deflection and energy versus deflection curves.

3 DYNAMIC COMPONENT TESTING ROUND 1 – STRONG SOIL

3.1 Purpose

Both the *Manual for Assessing Safety Hardware* (MASH) [9] and its predecessor, NCHRP Report No. 350 [7] require full-scale crash testing of soil-dependent systems to be conducted within a stiff, strong soil. Thus, it was logical to conduct bogie testing on the guardrail posts within a strong soil that satisfies the MASH requirement. Although three bogie tests were conducted on the U.S. standard rectangular SYP post in strong soil during Phase I of this project [6], additional bogie tests were desired to coincide with the testing of the round PP posts to ensure similar soil strength/stiffness in which to draw comparisons. Therefore, Round 1 of Phase II component testing consisted of both standard rectangular SYP posts and round PP posts.

3.2 Scope

Round 1 of the Phase II dynamic component testing consisted of five tests. Two tests, tests nos. SYPUS-1 and SYPUS-2, were conducted on U.S. standard G4(2W) 6-in. x 8-in. (152-mm x 203-mm) rectangular SYP posts embedded 43¼ in. (1,099 mm) in strong soil, as shown in Figures 2 and 3. The other three tests, test nos. PPUS-1 through PPUS-3, were conducted on 8⅝-in. (219-mm) diameter round PP posts embedded 36 in. (914 mm) in strong soil, as shown in Figure 4 through 6. These PP post dimensions reflected the estimated required post size to match the strength and soil resistance of the U.S. standard G4(2W) rectangular SYP post based on the results obtained during Phase I of this project. It should also be noted that the PP round post grading criteria were updated after Phase I of this project to include limits on the size and location of checks on the posts. A compacted, coarse crushed limestone material, as recommended by MASH [9], was utilized for all component tests.

The target impact conditions consisted of an impact speed of 20 mph (32 km/h) and an impact angle of 90 degrees, creating a classical "head-on" or full-frontal impact and strong-axis bending. To satisfy the U.S. G4(2W) standards, the posts were impacted 21.65 in. (550 mm) above the groundline for all tests. This load application height corresponded to the center of metric-height, W-beam guardrail systems. The complete test matrix for the first round of dynamic component testing is shown in Table 3. Material specifications, mill certifications, and certificates of conformity for the SYP and PP post materials are provided in Appendix A.

Table 3. Phase II, Round 1 Component Testing Matrix

Test No.	Post Material	Post Cross Section in. (mm)	Embedment Depth in. (mm)	Orientation (deg.)	Target Speed mph (km/h)
SYPUS-1	SYP	6 x 8 (152 x 203)	43¼ (1,099)	90	20 (32)
SYPUS-2	SYP	6 x 8 (152 x 203)	43¼ (1,099)	90	20 (32)
PPUS-1	PP	Ø8.68 (Ø220)	36 (914)	NA	20 (32)
PPUS-2	PP	Ø8.59 (Ø218)	36 (914)	NA	20 (32)
PPUS-3	PP	Ø8.56 (Ø217)	36 (914)	NA	20 (32)

Test Quantity	Post Species	Dimensions in. x in. [mm x mm]	Bogie No.	Bogie Speed mph [km/h]
2	Southern Yellow Pine	6x8 [152x203]	3	20 [32.2]

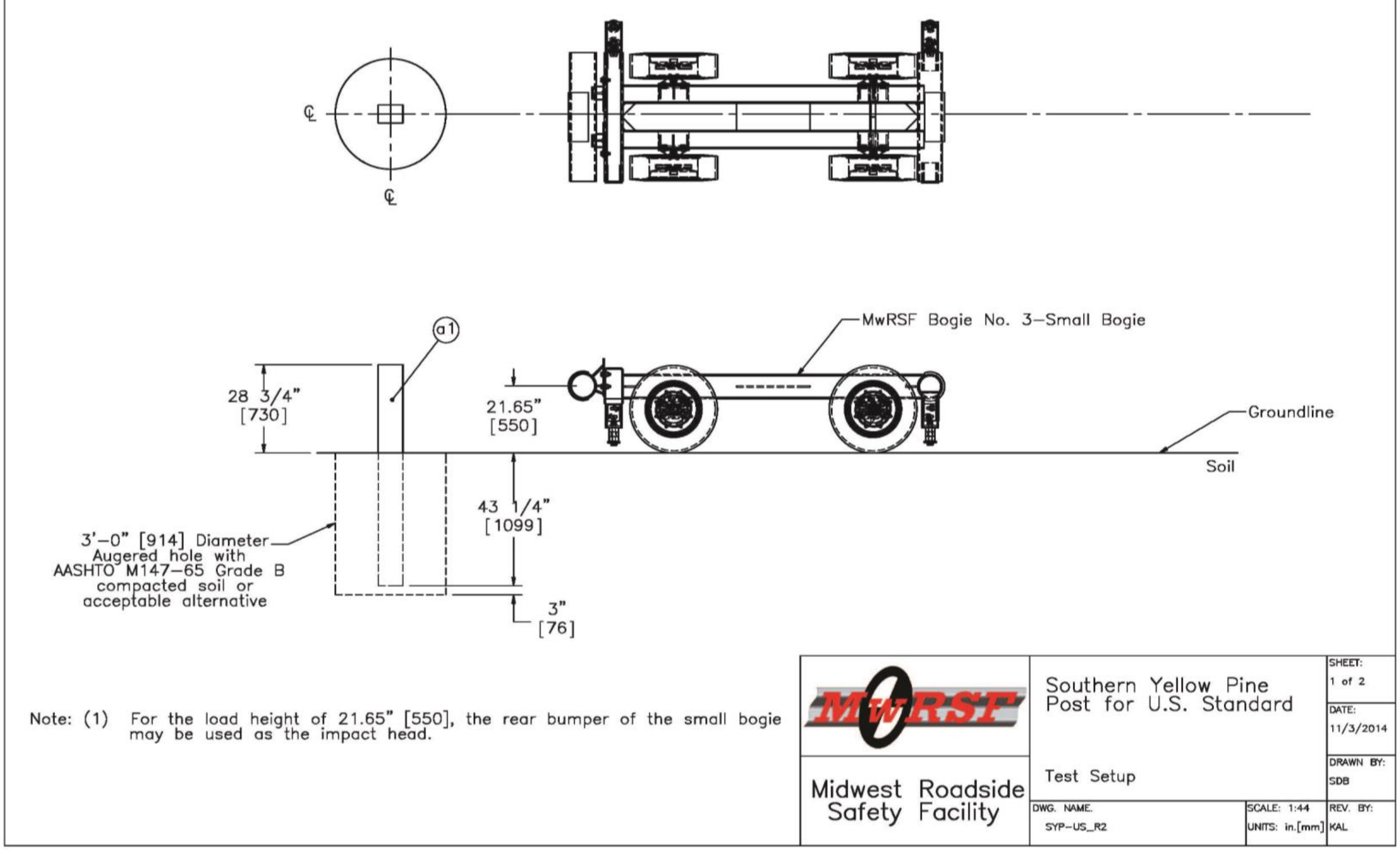


Figure 2. Bogie Testing Matrix and Setup, Test Nos. SYPUS-1 and SYPUS-2

Item No.	QTY.	Description	Material Specification	Hardware
a1	2	6"x8"x72" [152x203x1829] Southern Yellow Pine (SYP) Post	SYP Grade No. 1 or better	PDE02

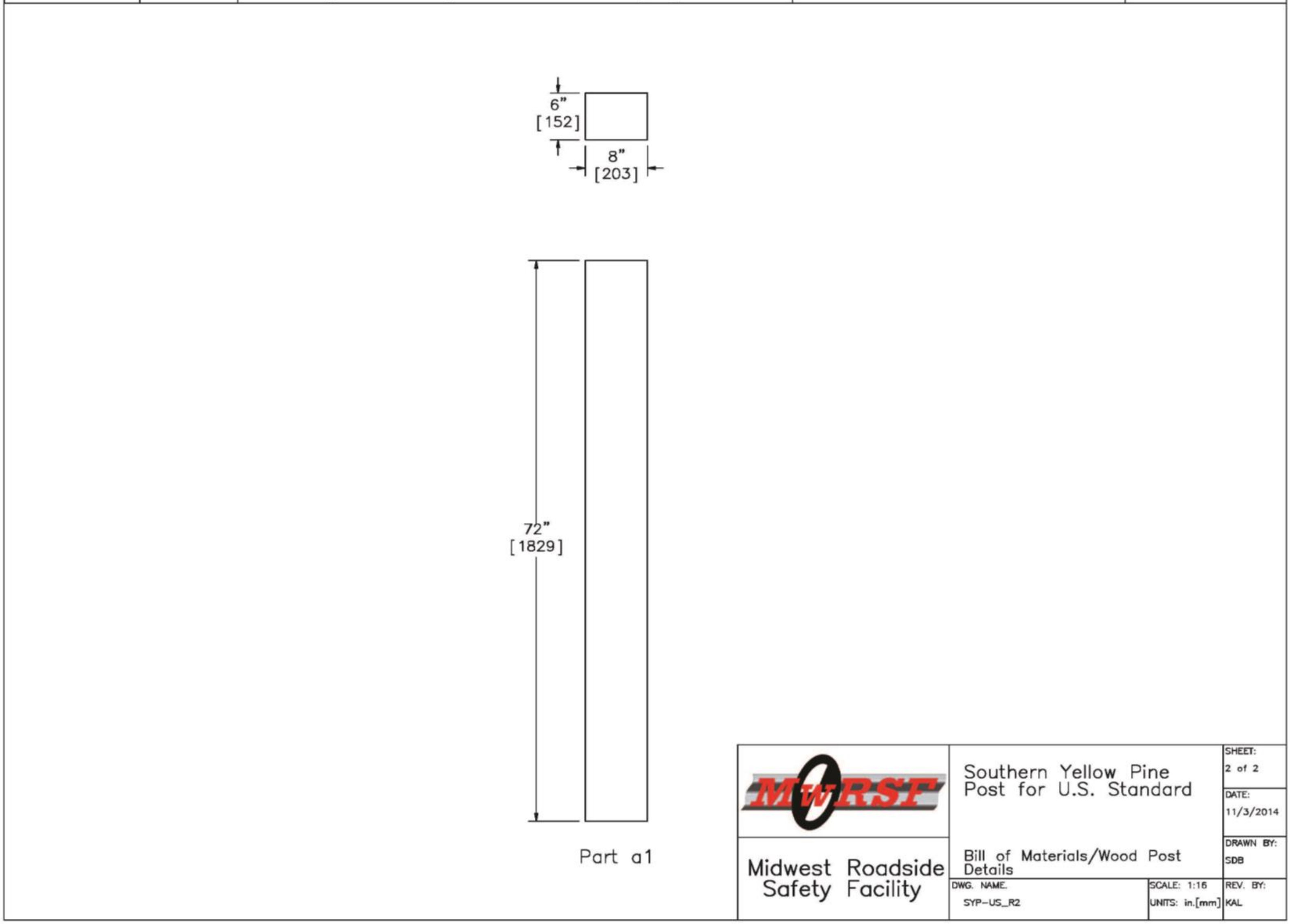
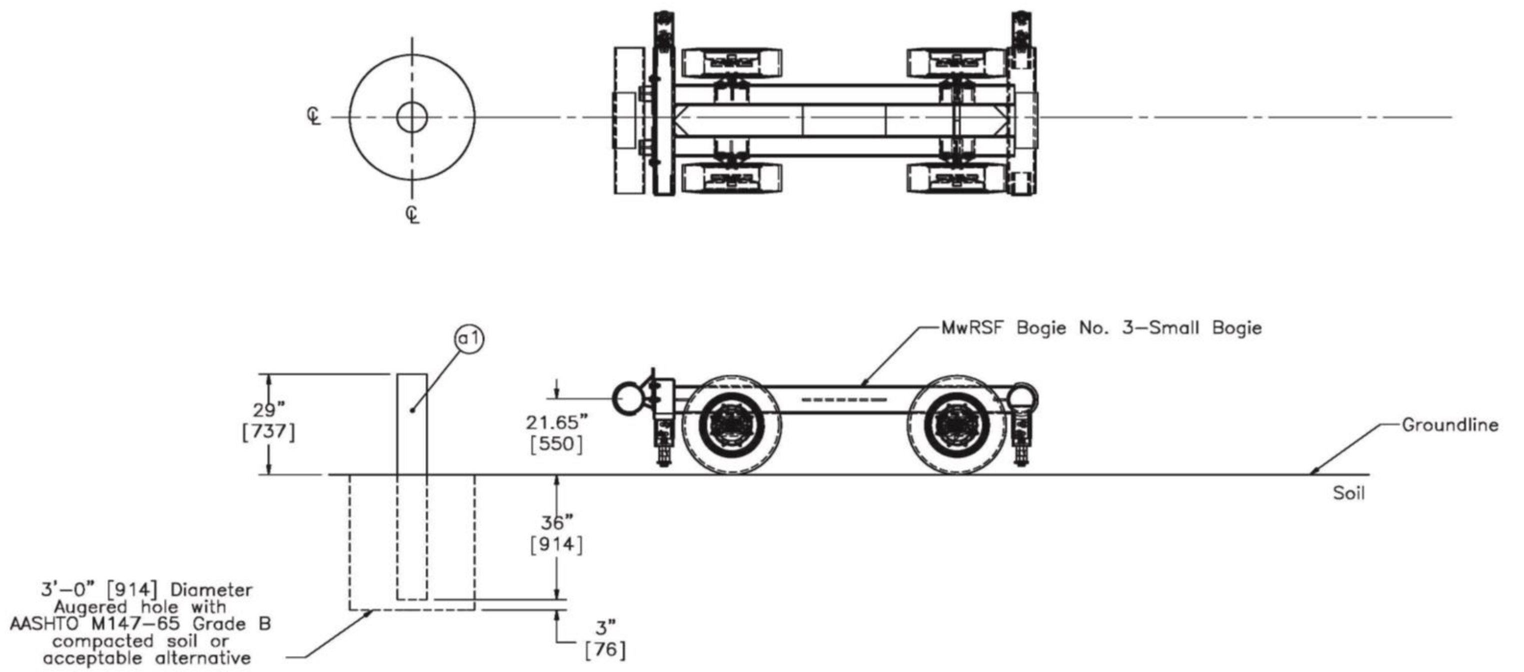


Figure 3. Post Details, Test Nos. SYPUS-1 and SYPUS-2

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	Ponderosa Pine	8 5/8 [219]	36 [914]	29 [737]	65 [1651]	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) Round posts shall be soaked before testing and allowed to air dry for two days in a warm environment.

(3) The critical zone diameter, measured 37" [940] from the top of post, shall be greater than or equal to 8 5/8" [219]. It may be acceptable for the groundline diameter to measure greater than or equal to 8 1/2" [216] as long as critical zone diameter is met and PI approves post selection.

(4) Post tests shall not be performed when temperatures are below freezing or with frozen, compacted soil.

MwRSF Midwest Roadside Safety Facility	Ponderosa Pine Post Alternatives for U.S. Standards		SHEET: 1 of 3 DATE: 11/3/2014
	Test Setup		DRAWN BY: SDB
	DWG. NAME. PP-US_R7	SCALE: 1:44 UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 4. Bogie Testing Matrix and Setup, Test Nos. PPUS-1 through PPUS-3

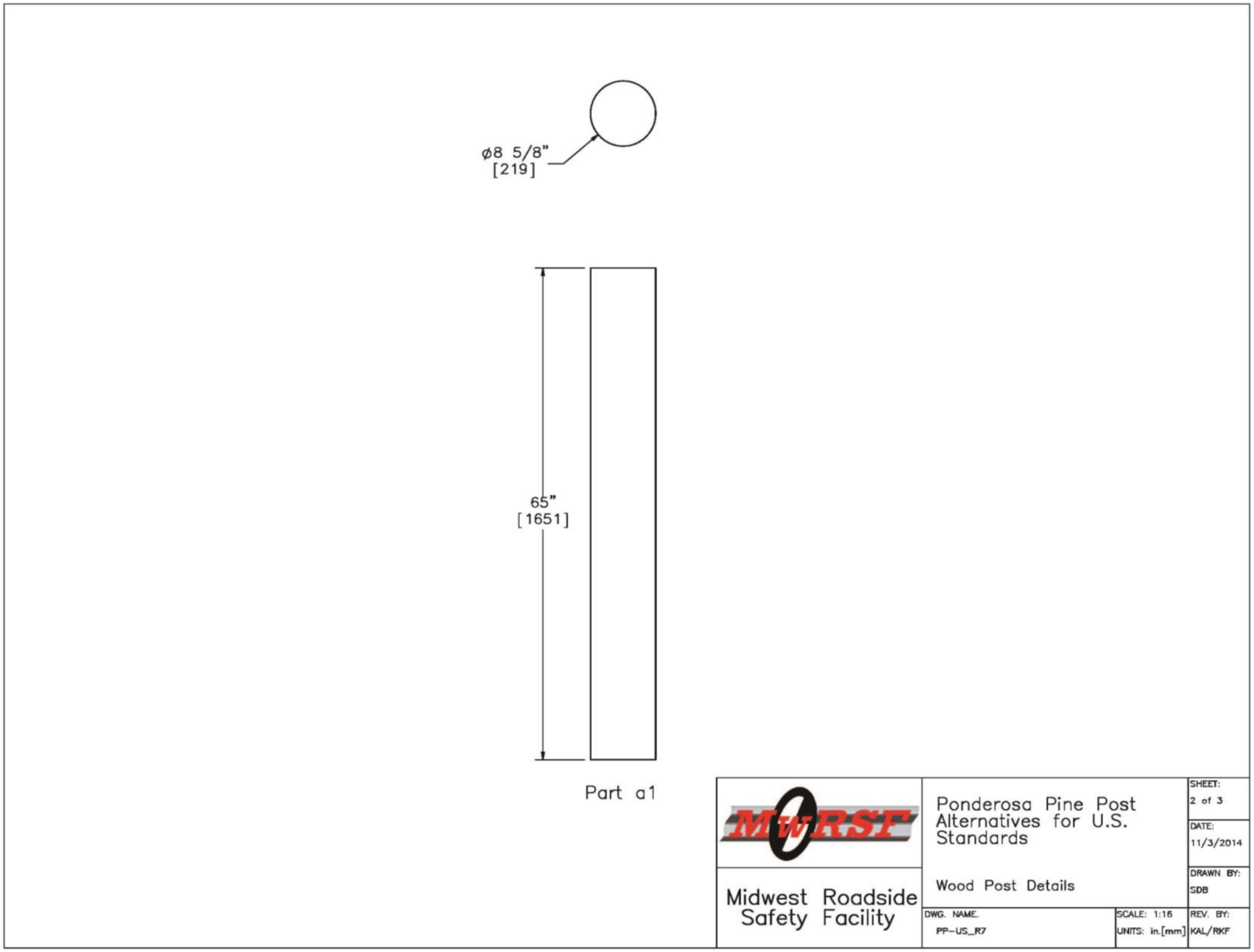


Figure 5. Post Details, Test Nos. PPUS-1 through PPUS-3

Item No.	QTY.	Description	Material Specification	Hardware
a1	3	8 5/8" [219] Diameter by 65" [1651] Long Ponderosa Pine (PP) Post	See fabrication criteria 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 8 5/8–in. (219) diameter guardrail post will be a minimum of 65–in. (1651) long. The use of peeler cores is prohibited.

Groundline:
The groundline, for the purpose of applying these restrictions of ANSI 05.1 that reference the groundline, shall be defined as being located 36–in. (914) from the butt end of each post.

Size:
The size of the posts shall be classified based on their diameter at the groundline and their length. The groundline diameter shall be specified by diameter in 1/8–in. (3) breaks. The length shall be specified in 1–in. (25) 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 minimum groundline diameter of the PP posts shall be 8 5/8–in. (219) with an upper limit of 9 1/8–in. (232).

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 1 1/4–in. (32) at any point. Posts shall be free from reverse bends.

Splits, Checks, and Shakes:
Splits or ring shakes are not permitted in the top 2/3 of the post. Checks are not permitted in the top 2/3 of the post if wider than 1/3 of the diameter if dry and wider than 3/8 of the diameter if not dry. Splits exceeding the diameter in length are not permitted in the bottom 1/3 of the post. A shake or check is permitted in the bottom 1/3 of the post as long as it is not wider than 1/2 of the butt diameter. (Note – check size is determined as the average measured penetration over its length.)

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3 1/2–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 3/4–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 1/4 of the radius.

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

MwRSF Midwest Roadside Safety Facility	Ponderosa Pine Post Alternatives for U.S. Standards	SHEET: 3 of 3 DATE: 11/3/2014
	Bill of Materials and Grading Criteria	DRAWN BY: SDB
	DWG. NAME. PP–US_R7 / SCALE: NONE UNITS: in.[mm]	REV. BY: KAL/RKF

Figure 6. Ponderosa Pine Grading Criteria, Test nos. PPUS-1 through PPUS-3

3.3 Test Results

Results from all five of the dynamic component tests are discussed in the following sections. The force and displacement data shown in this section were calculated from the DTS and SLICE-2 accelerometer units. Results for all accelerometers used on each test are provided in Appendix B.

3.3.1 Test No. SYPUS-1

During test no. SYPUS-1, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) SYP post at a speed of 23.2 mph (37.3 km/h). Upon impact, the post began to rotate backward. However, the post fractured 0.034 seconds after impact at a deflection of 12.2 in. (310 mm). Post-test examination revealed the post had fractured approximately 5 in. (127 mm) below the groundline. Additionally, the bottom half of the post split vertically into two pieces.

Force versus deflection and energy versus deflection curves from the DTS accelerometer data are shown in Figure 7. A peak force of 17.7 kips (78.7 kN) was observed at 4.0 in. (102 mm) of deflection. Following this peak, the post began to crack, and the force declined. The post continued to provide resistance until fracture was completed at a deflection of 12.2 in. (310 mm). A total of 146.0 kip-in. (16.5 kJ) of energy was absorbed by the post and soil by the conclusion of post fracture. Time-sequential and post-impact photographs are shown in Figure 8.

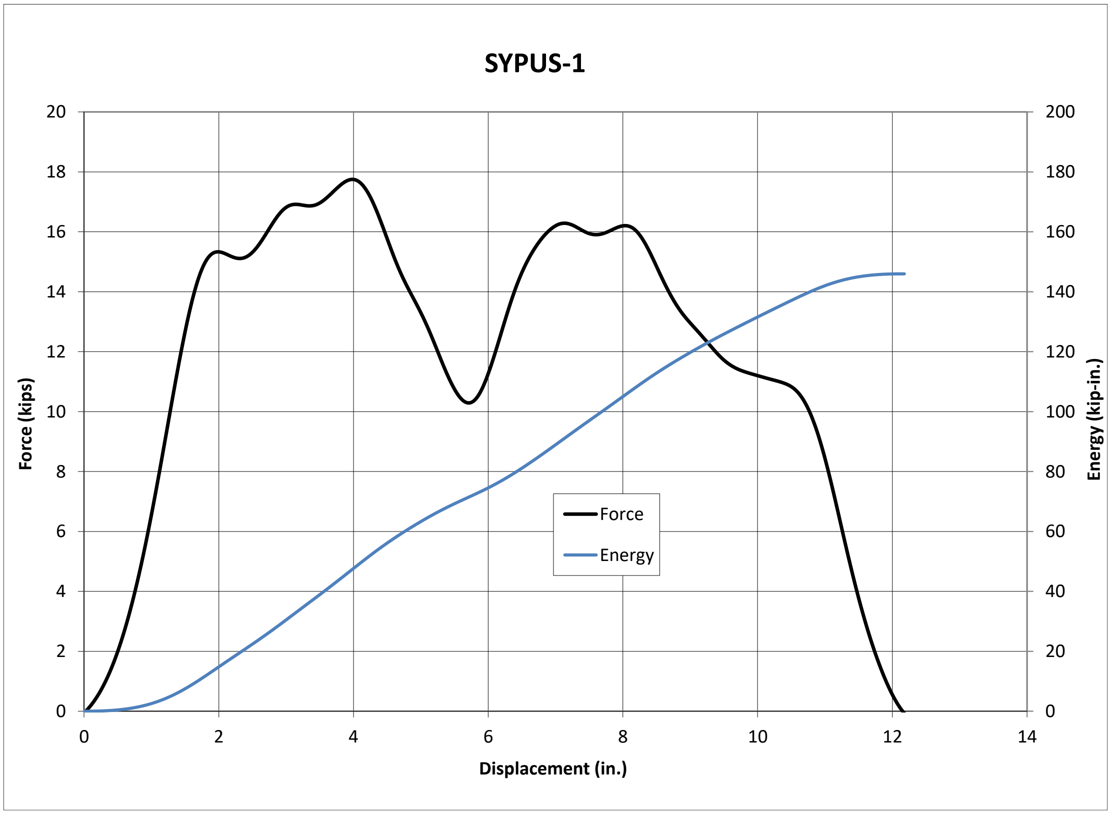


Figure 7. Force vs. Deflection and Energy vs. Deflection, Test No. SYPUS-1

Figure 8. Time-Sequential and Post-Impact Photographs, Test No. SYPUS-1

3.3.2 Test No. SYPUS-2

During test no. SYPUS-2, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) SYP post at a speed of 19.6 mph (31.5 km/h). Upon impact, the post began to rotate backward. However, the post fractured 0.020 seconds after impact at a deflection of 7.8 in. (198 mm). Post-test examination revealed the post had fractured approximately 8 in. (203 mm) below the groundline.

Force vs. deflection and energy vs. deflection curves from the DTS accelerometer data are shown in Figure 9. A peak force of 12.7 kips (56.5 kN) was observed at 6.0 in. (152 mm) of deflection. Following this peak, the post fractured, and the force rapidly dropped to zero. A total of 63.6 kip-in. (7.2 kJ) of energy was absorbed by the post by the conclusion of post fracture at 7.8 in. (198 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 10.

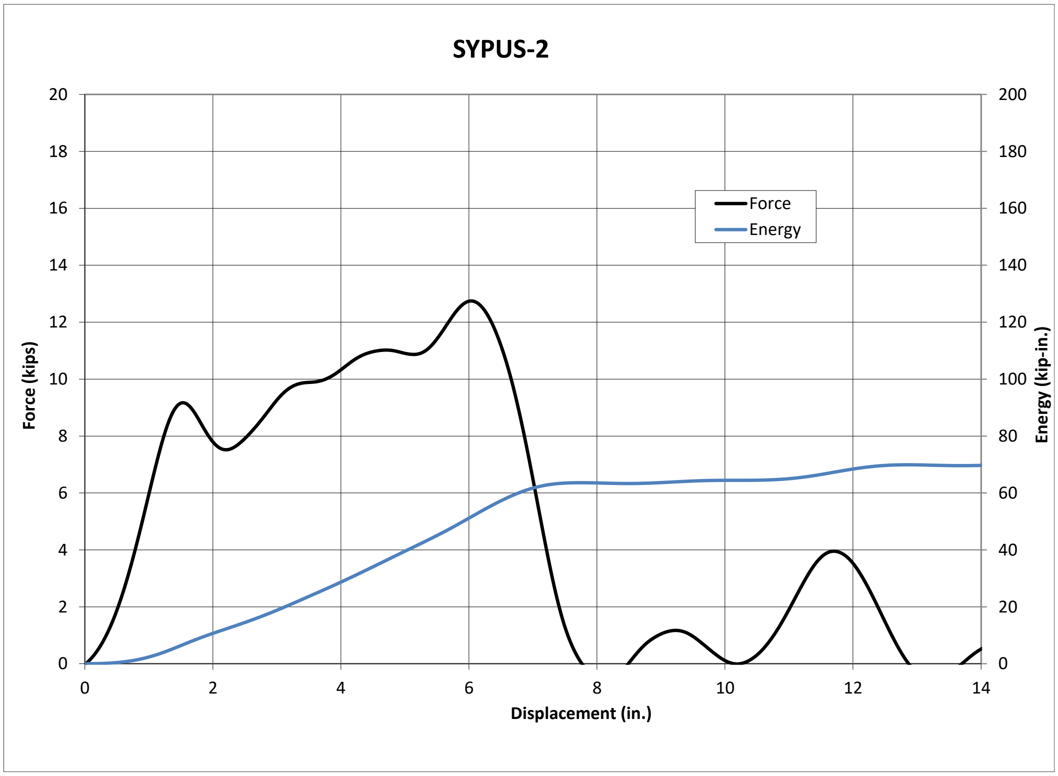


Figure 9. Force vs. Deflection and Energy vs. Deflection, Test No. SYPUS-2

IMPACT

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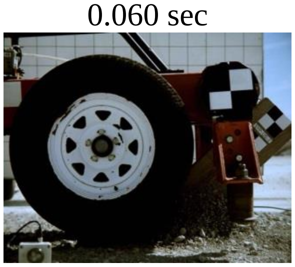
0.060 sec



0.090 sec

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Figure 10. Time-Sequential and Post-Impact Photographs, Test No. SYPUS-2

3.3.3 Test No. PPUS-1

During test no. PPUS-1, the bogie impacted the 8.68-in. (220-mm) diameter PP post at a speed of 21.6 mph (34.8 km/h). Upon impact, the post began to rotate backward. However, the post fractured 0.029 seconds after impact at a deflection of 10.1 in. (257 mm). Post-test examination revealed the post had fractured approximately 3 in. (76 mm) below the groundline.

Force vs. deflection and energy vs. deflection curves from the SLICE-2 accelerometer data are shown in Figure 11. A peak force of 18.0 kips (80.1 kN) was observed at 6.3 in. (160 mm) of deflection. Shortly following this peak, the post fractured, and the force rapidly dropped to zero. A total of 128.6 kip-in. (14.5 kJ) of energy was absorbed by the post by the conclusion of post fracture at 10.1 in. (257 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 12.

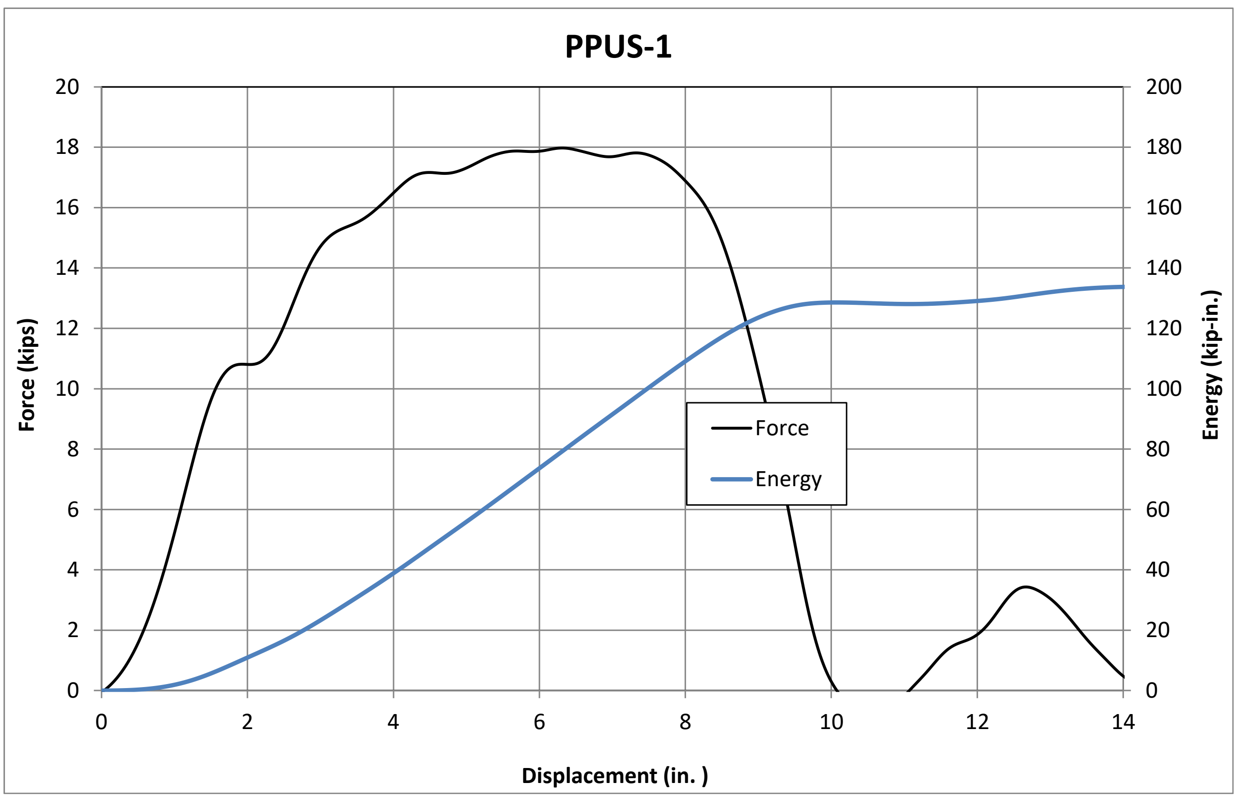
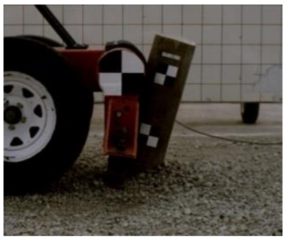


Figure 11. Force vs. Deflection and Energy vs. Deflection, Test No. PPUS-1

IMPACT



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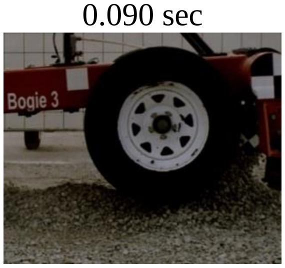

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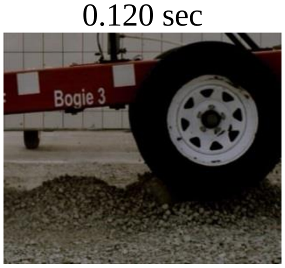

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Figure 12. Time-Sequential and Post-Impact Photographs, Test No. PPUS-1

3.3.4 Test No. PPUS-2

During test no. PPUS-2, the bogie impacted the 8.59-in. (218-mm) diameter PP post at a speed of 19.0 mph (30.6 km/h). Upon impact, the post began to rotate backward. However, the post fractured 0.032 seconds after impact at a deflection of 9.6 in. (244 mm). Post-test examination revealed the post had fractured approximately 2 in. (51 mm) below the groundline.

Force vs. deflection and energy vs. deflection curves from the SLICE-2 accelerometer data are shown in Figure 13. The resistive force slowly increased until a peak force of 14.6 kips (64.9 kN) was observed at 7.8 in. (198 mm) of deflection. Following this peak, the post fractured, and the force rapidly dropped to zero. A total of 100.7 kip-in. (11.4 kJ) of energy was absorbed by the post by the conclusion of post fracture at 9.6 in. (244 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 14.

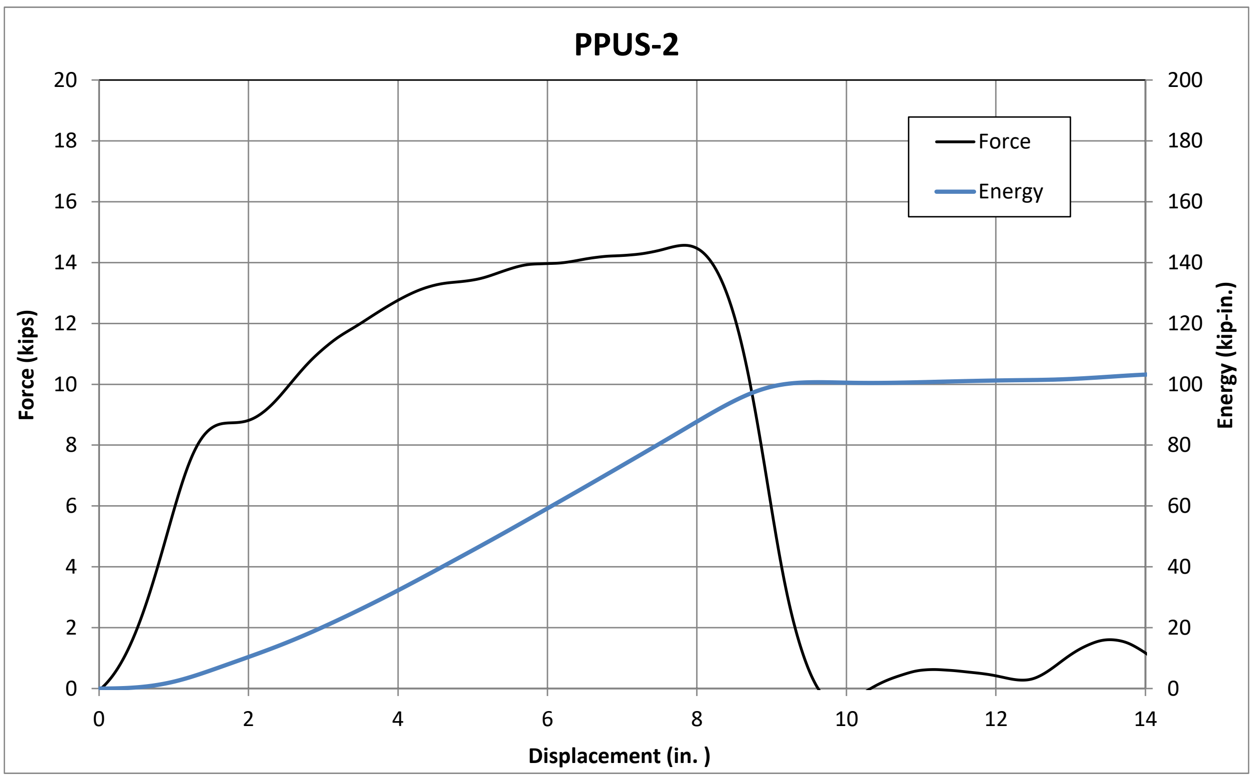
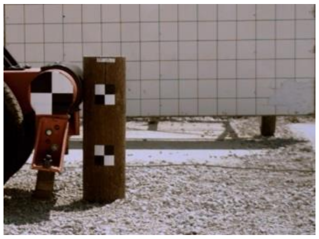
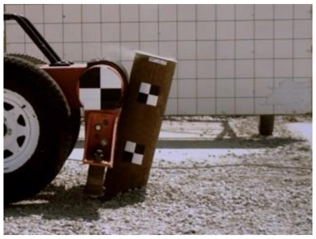


Figure 13. Force vs. Deflection and Energy vs. Deflection, Test No. PPUS-2



IMPACT



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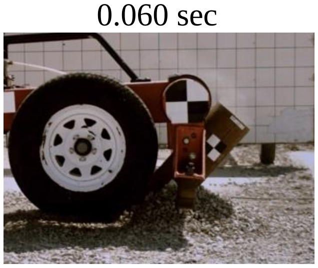

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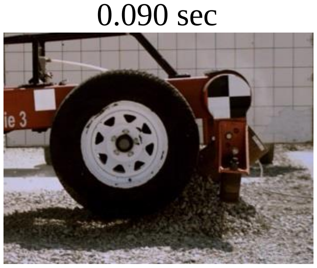

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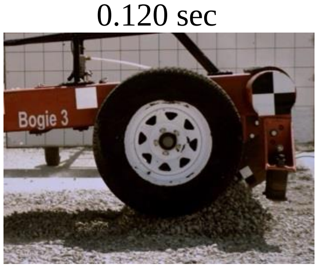

0.150 sec

Figure 14. Time-Sequential and Post-Impact Photographs, Test No. PPUS-2

3.3.5 Test No. PPUS-3

During test no. PPUS-3, the bogie impacted the 8.56-in. (217-mm) diameter PP post at a speed of 19.5 mph (31.4 km/h). Upon impact, the post began to rotate backward. However, the post quickly fractured 0.013 seconds after impact at a deflection of 4.4 in. (112 mm). Post-test examination revealed the post had fractured approximately 8 in. (203 mm) below the groundline.

Force vs. deflection and energy vs. deflection curves from the SLICE-2 accelerometer data are shown in Figure 15. The resistive force increased rapidly to a peak of 9.3 kips (41.4 kN), observed at 2.7 in. (69 mm) of deflection. Following this peak, the post fractured, and the force rapidly dropped to zero. A total of 23.9 kip-in. (2.7 kJ) of energy was absorbed by the post by the conclusion of post fracture at 4.4 in. (112 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 16.

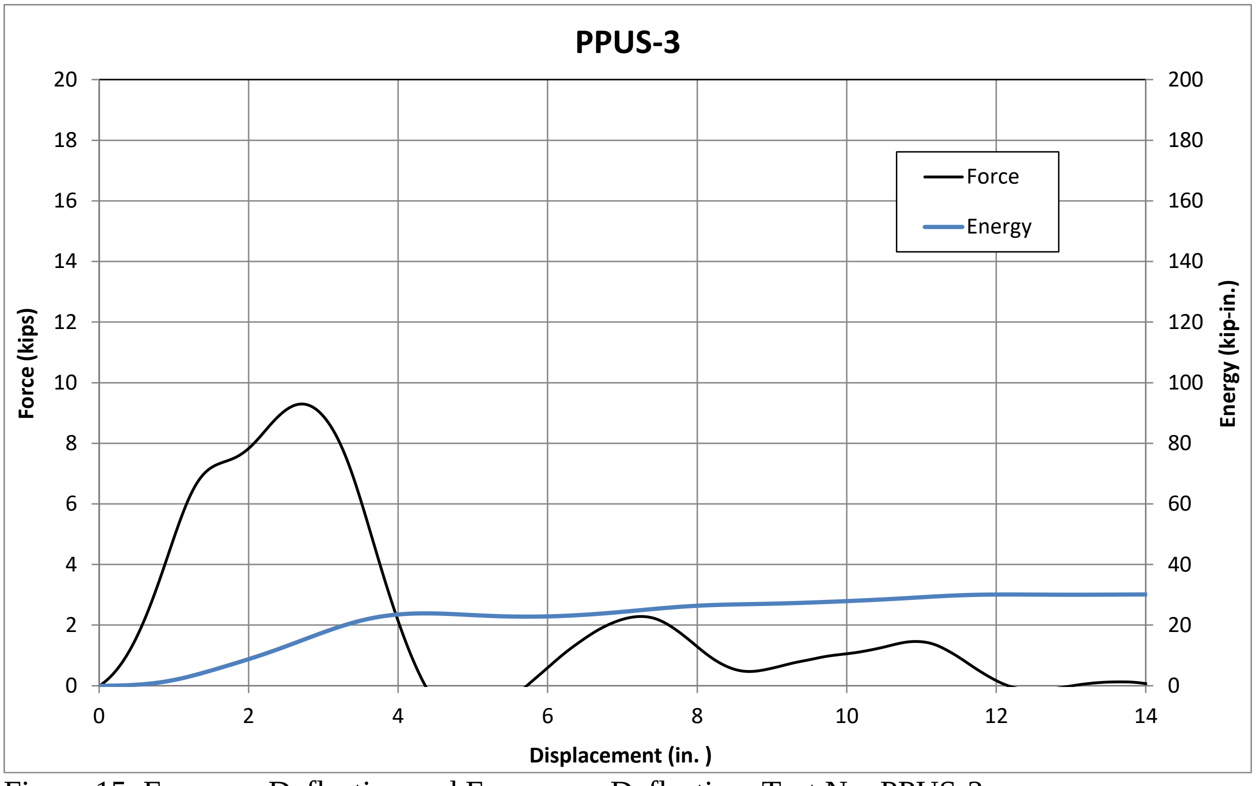

Figure 15. Force vs. Deflection and Energy vs. Deflection, Test No. PPUS-3

IMPACT

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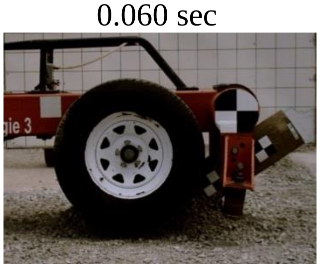

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Figure 16. Time-Sequential and Post-Impact Photographs, Test No. PPUS-3

3.4 Discussion

Round 1 of component testing consisted of five tests conducted within strong soil, two of these tests on 6-in. x 8-in. (152-mm x 203-mm) SYP posts with 43¼-in. (1,099-mm) embedment depths and three tests on 8⅝-in. (219-mm) diameter PP posts with 36-in. (914-mm) embedment depths. Results from the Round 1 tests are summarized in Table 4. Force versus deflection and energy versus deflection plots are shown in Figures 17 and 18, respectively.

Each of the five tests resulted in the timber post fracturing quickly with only minor soil displacements. Subsequently, it was difficult to make energy absorption comparisons between the posts. However, the peak forces (fracture loads) from the tests provided a good comparison of the ultimate strength of the two post types. As shown in Table 4, the average peak force observed for the 8⅝-in. (219-mm) diameter PP posts was within 8 percent of the G4(2W) rectangular SYP posts. Additionally, there was only a 20 percent difference between the average displacements at the time of fracture between the two post types.

Looking more closely at the individual tests, the extremely quick fracture of the post in test no. PPUS-3 appeared to be significantly different from the other test results. Test no. PPUS-3 had a peak force over 30 percent lower than the other PP posts, and the displacement at the time of fracture was less than half that of the other posts. Thus, the post from test no. PPUS-3 was thought to be an outlier. If the results from test no. PPUS-3 are removed from consideration, the average peak forces and displacements at fracture for the PP posts become 16.3 kips (72.5 kN) and 9.9 in. (251 mm), respectively. These values differ from the SYP post values by only 7 percent and 2 percent, respectively.

To strengthen the argument that the two post types have similar ultimate capacities, results from testing on similarly-sized posts were sought from the previous phase of this project

[6]. As shown in Table 5, three tests on 6-in. x 8-in. (152-mm x 203-mm) SYP posts with 43¼-in. (1,099-mm) embedment depths and five tests on round PP posts with diameters between 8½ in. (216 mm) and 8¾ in. (222 mm) were conducted during Phase I of the project. Although some of the PP posts had slightly different embedment depths, they still provided insight to the strength capacity of the round PP cross section. With the inclusion of these eight tests, the average peak forces for the rectangular SYP posts and the round PP posts were very similar at 15.8 kips (70.3 kN) and 15.6 kips (69.4 kN), respectively. Additionally, the post displacement at the time of fracture differed by only 1.2 in. (30 mm) between the post types. Therefore, an 8⅝-in. (219-mm) diameter PP post was deemed to have strength equivalent to the U.S. standard rectangular SYP post utilized in the G4(2W) guardrail system.

Table 4. Round 1 Component Testing Results - Strong Soil

Test No.	Wood Species	Post Cross-Section in. (mm)	Post Embedment in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Average Force kips (kN)				Absorbed Energy kip-in. (kJ)				Post-Soil Behavior	Deflection at Fracture Initiation in. (mm)	Deflection at Fracture Completion in. (mm)
						@ 5"	@ 10"	@ 15"	@ 20"	@ 5"	@ 10"	@ 15"	@ 20"			
SYPUS-1	SYP	6 x 8 (152 x 203)	43 1/4 (1,099)	23.2 (37.3)	17.7 (78.7)	12.7 (56.4)	13.2 (58.7)	NA	NA	63.6 (7.2)	131.6 (14.9)	NA	NA	Post Fracture	10.3 (262)	12.2 (310)
SYPUS-2	SYP	6 x 8 (152 x 203)	43 1/4 (1,099)	19.6 (31.5)	12.7 (56.5)	8.2 (36.5)	NA	NA	NA	41.1 (4.6)	NA	NA	NA	Post Fracture	6.0 (152)	7.8 (198)
AVERAGE					**15.2 (67.6)**	**10.4 (46.4)**	**13.2 (58.7)**	-	-	**52.4 (5.9)**	**131.6 (14.9)**	-	-			**10.0 254**
PPUS-1	PP	Ø 8.68 (Ø 220)	36 (914)	21.6 (34.8)	18.0 (80.1)	11.3 (50.3)	12.9 (57.2)	NA	NA	56.1 (6.3)	128.6 (14.5)	NA	NA	Post Fracture	7.8 (198)	10.1 (257)
PPUS-2	PP	Ø 8.59 (Ø 218)	36 (914)	19.0 (30.6)	14.6 (64.9)	9.2 (40.9)	NA	NA	NA	45.7 (5.2)	NA	NA	NA	Post Fracture	8.0 (203)	9.6 (244)
PPUS-3	PP	Ø 8.56 (Ø 217)	36 (914)	19.5 (31.4)	9.3 (41.4)	4.6 (20.5)	NA	NA	NA	23.2 (2.6)	NA	NA	NA	Post Fracture	2.7 (69)	4.4 (112)
AVERAGE					**14.0 (62.1)**	**8.4 (37.2)**	**12.9 (57.2)**	-	-	**41.7 (4.7)**	**128.6 (14.5)**	-	-			**8.0 204**

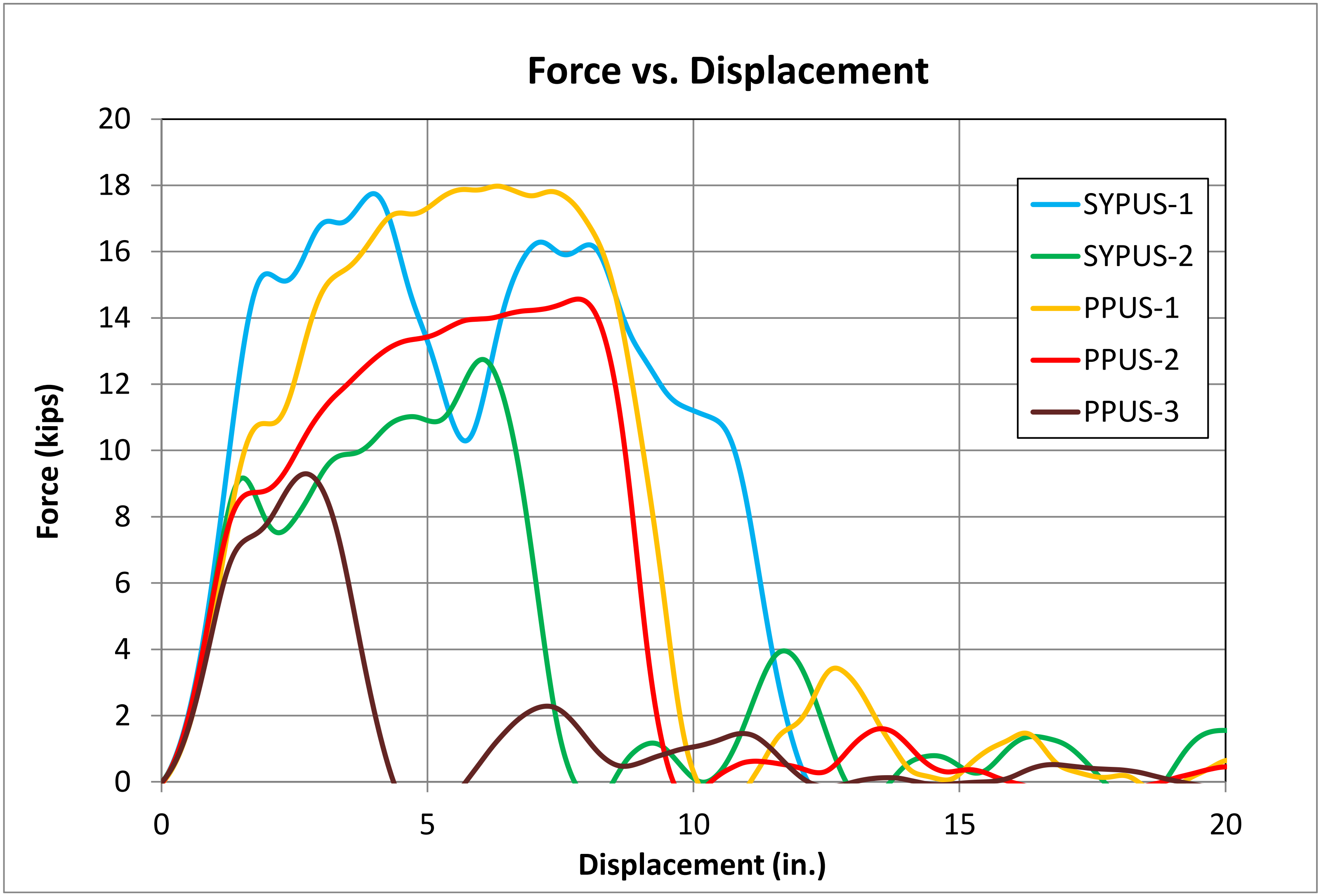


Figure 17. Force vs. Displacement Plot, Round 1 Testing Results - Strong Soil

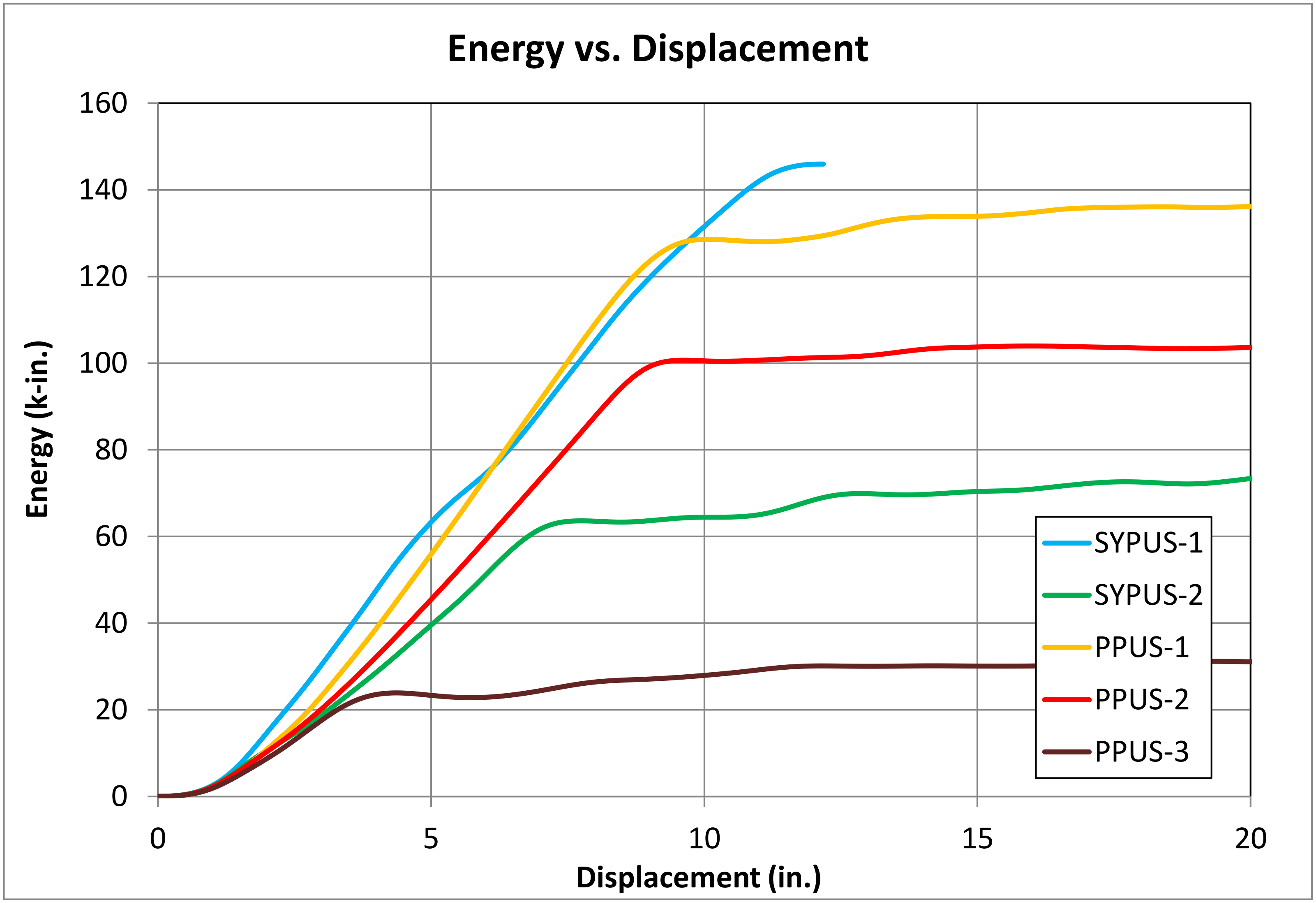


Figure 18. Energy vs. Displacement Plot, Round 1 Testing Results - Strong Soil

Table 5. Peak Force Comparison for Similar Posts, Phases I and II

Test No.	Timber Species	Post Cross Section in. (mm)	Post Embedment in. (mm)	Peak Force kips (kN)	Failure Mechanism	Deflection at Fracture in. (mm)
*AZSYP-1	SYP	6 x 8 (152 x 203)	43¼ (1,099)	18.5 (82.3)	Post Fracture	5 (127)
*AZSYP-2	SYP	6 x 8 (152 x 203)	43¼ (1,099)	13.5 (60.1)	Post Fracture	8.5 (216)
*AZSYP-3	SYP	6 x 8 (152 x 203)	43¼ (1,099)	16.4 (73.0)	Rotation in Soil	NA
SYPUS-1	SYP	6 x 8 (152 x 203)	43¼ (1,099)	17.7 (78.7)	Post Fracture	12.2 (310)
SYPUS-2	SYP	6 x 8 (152 x 203)	43¼ (1,099)	12.7 (56.5)	Post Fracture	7.8 (198)
Rectangular SYP Post Average				**15.8 (70.1)**		**8.4 (213)**
*AZPP-2	PP	Ø 8.67 (Ø 220)	37 (940)	14.3 (63.6)	Rotation in Soil	NA
*AZPP-4	PP	Ø 8.55 (Ø 217)	35 (889)	17.0 (75.6)	Post Fracture	5.7 (145)
*AZPP-5	PP	Ø 8.55 (Ø 217)	35 (889)	14.2 (63.2)	Rotation in Soil	NA
*AZPP-7	PP	Ø 8.67 (Ø 220)	35 (889)	16.5 (73.4)	Post Fracture	6.4 (163)
*AZPP-8	PP	Ø 8.71 (Ø 221)	35 (889)	20.5 (91.2)	Rotation in Soil	NA
PPUS-1	PP	Ø 8.68 (Ø 220)	36 (914)	18.0 (80.1)	Post Fracture	10.1 (257)
PPUS-2	PP	Ø 8.59 (Ø 218)	36 (914)	14.6 (64.9)	Post Fracture	9.6 (244)
PPUS-3	PP	Ø 8.56 (Ø 217)	36 (914)	9.3 (41.4)	Post Fracture	4.4 (112)
Round PP Post Average				**15.6 (69.2)**		**7.2 (184)**

* Tests Conducted during Phase I of Project [6]

4 DYNAMIC COMPONENT TESTING ROUND 2 –WEAK SOIL

4.1 Purpose

Round 1 of the Phase II component testing demonstrated that an 8⅝-in. (219-mm) diameter PP post has an ultimate strength equivalent to that of the 6-in. x 8-in. (152-mm x 203-mm) SYP post utilized in the G4(2W) guardrail system. However, each of the component tests resulted in post fracture and prevented a complete assessment of the soil resistive forces applied to the different cross sections and embedment depths. Therefore, additional testing was desired with both post types installed in a less stiff soil that would allow the posts to rotate and absorb more energy. Additionally, it was felt that a less stiff soil may be more representative of the soil conditions supporting real-world system installations.

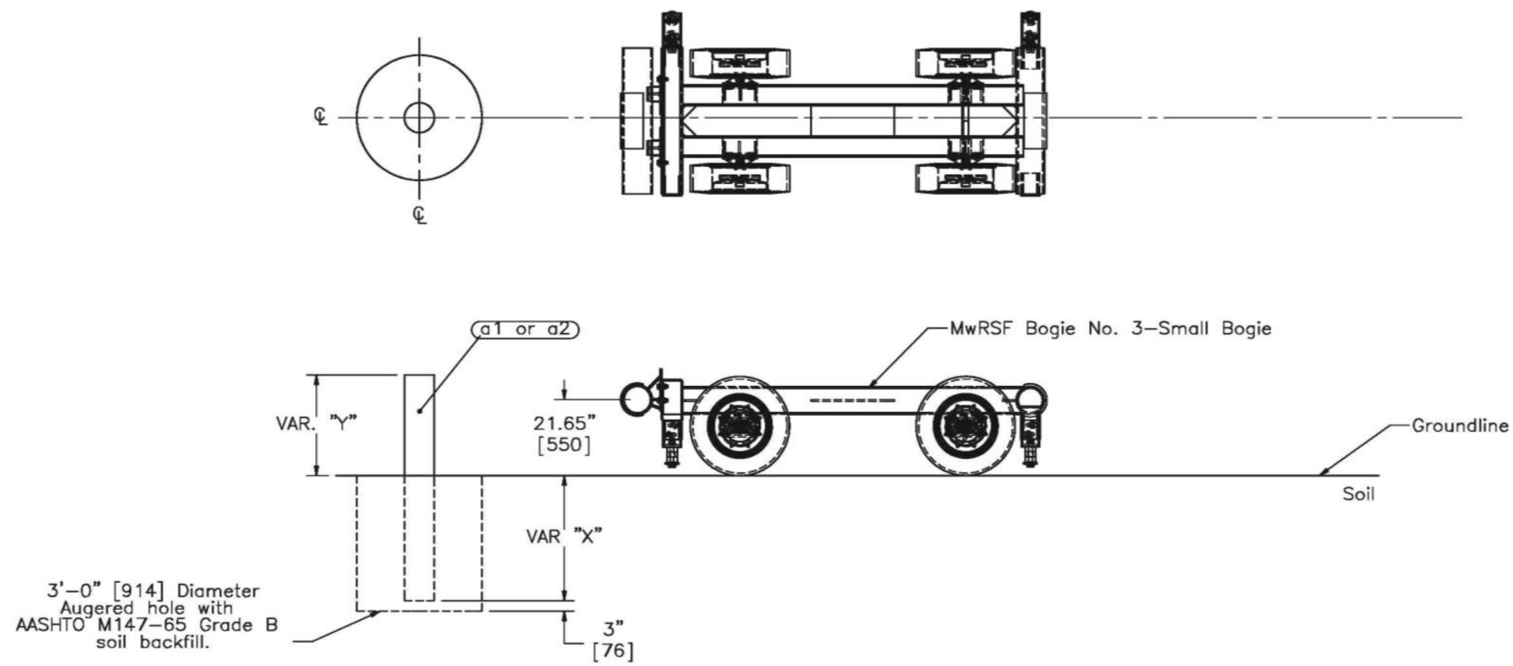
4.2 Scope

Round 2 of dynamic component testing consisted of two tests on 8⅝-in. (219-mm) diameter PP posts with 36-in. (914-mm) embedment depths and two tests on 6-in. x 8-in. (152-mm x 203-mm) SYP posts with 43¼-in. (1,099-mm) embedment depths. All four posts were installed in a coarse crushed limestone soil similar to the previous Round 1 installations. However, the soil was only moderately compacted to obtain a soil resistance with approximately 30 percent less strength than the strong soil used in Phase II Round 1. The impact criteria remained the same with a targeted impact speed of 20 mph (32 km/h) and an impact height of 21.65 in. (550 mm). Finally, the same PP grading criteria was carried over from the previous round of testing. The bogie testing matrix and the test setup are shown in Table 7 and Figures 19 through 21, respectively. Material specifications, mill certifications, and certificates of conformity for the round PP post material are provided in Appendix A.

Table 6. Phase II Round 2 Component Testing Matrix

Test No.	Post Material	Post Cross-Section in. (mm)	Embedment Depth in. (mm)	Orientation (deg.)	Target Speed mph (km/h)
PPW-1	PP	Ø8.55 (Ø217)	36 (914)	NA	20 (32)
PPW-2	PP	Ø8.48 (Ø215)	36 (914)	NA	20 (32)
PPSYPW-1	SYP	6 x 8 (152 x 203)	43¼ (1,099)	90	20 (32)
PPSYPW-2	SYP	6 x 8 (152 x 203)	43¼ (1,099)	90	20 (32)

Test Quantity	Post Species	Groundline Cross–Section in. [mm]	Embedment Depth "X" in. [mm]	Top of Post Height "Y" in. [mm]	Post Length in. [mm]	Load Height in. [mm]	Bogie No.	Bogie Speed mph [km/h]
2	Ponderosa Pine	ϕ8 5/8 [219]	36 [914]	29 [737]	65 [1651]	21.65 [550]	3	20 [32.2]
2	S.Y.P.	6"x8" [152x203]	43 1/4 [1099]	28 3/4 [730]	72 [1829]	21.65 [550]	3	20 [32.2]



Notes: (1) Soil shall be compacted such that strength approximately ranges between 60–80 percent of H.E.–8 strength. Discuss compaction method with P.I. prior to installation/testing.

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

(3) The critical zone diameter for round posts, measured 37" [940] from the top of the post, shall be 8 5/8" [219], with an approximate allowable tolerance of 1/8" [3].

(4) Rectangular 6"x8" [152x203] SYP Posts have an allowable tolerance of +/– 1/8" [3] for cross section dimensions.

MwRSF

Midwest Roadside Safety Facility

Ponderosa Pine and Southern Yellow Pine Post Alternatives for U.S. Standards

Test Setup

SHEET: 1 of 3

DATE: 11/3/2014

DRAWN BY: JEK/KLK/SDB

DWG. NAME. PP–SYP–US_R3

SCALE: 1:44

UNITS: in.[mm]

REV. BY: SKR/RKF

Figure 19. Bogie Testing Matrix and Setup – Testing in Weak Soil

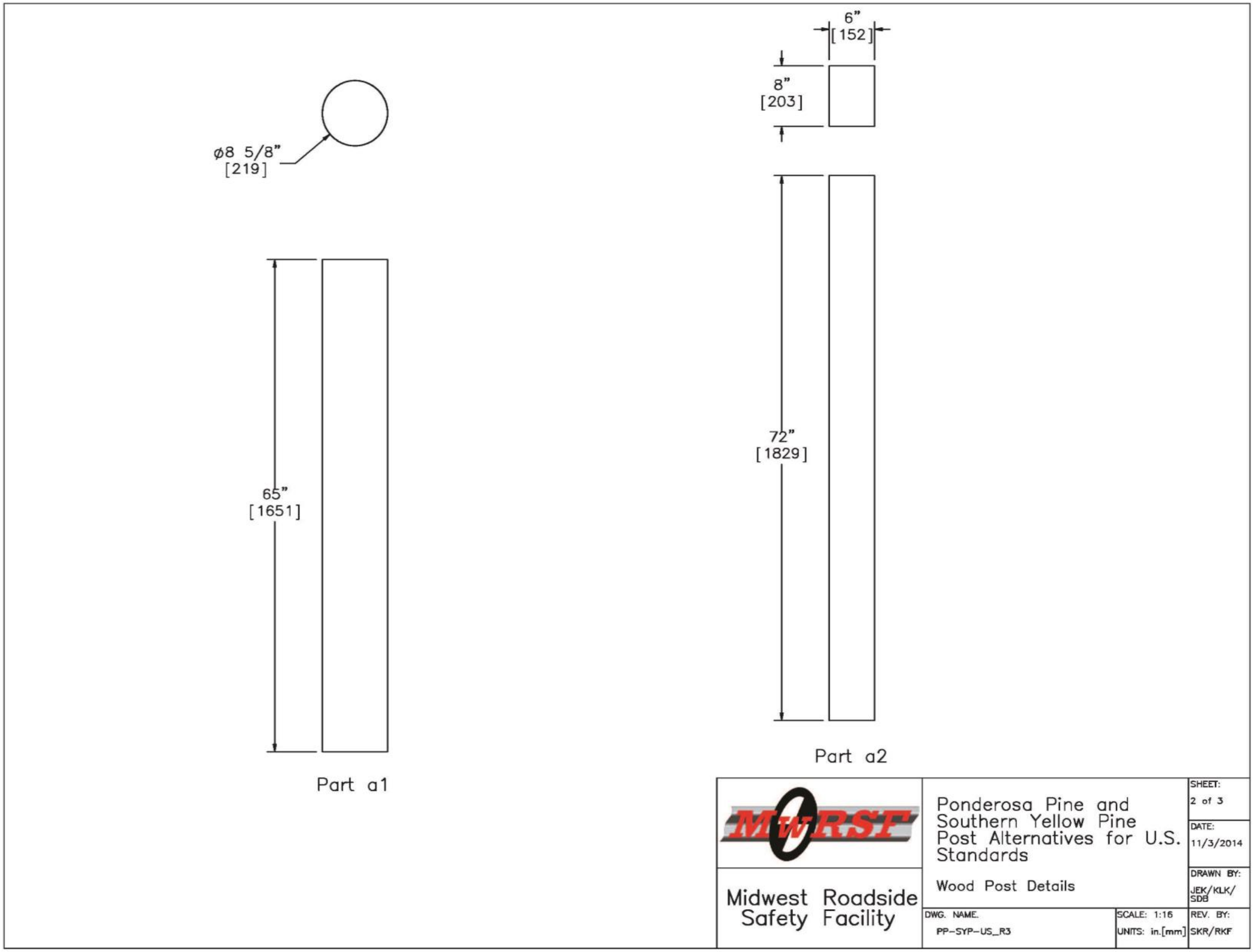


Figure 20. Post Detail– Testing in Weak Soil

Item No.	QTY.	Description	Material Specification	Hardware
a1	2	8 5/8" [219] Diameter by 65" [1651] Long Ponderosa Pine (PP) Post	See fabrication criteria below	–
a2	2	6"x8" by 72" Long [152x203x1829] Southern Yellow Pine (SYP) Post	CCA Treated SYP Grade No. 1 or better	PDE02

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 8 5/8–in. (219) diameter guardrail post will be a minimum of 65–in. (1651) long. The use of peeler cores is prohibited.

Groundline:
The groundline, for the purpose of applying these restrictions of ANSI 05.1 that reference the groundline, shall be defined as being located 36–in. (914) from the butt end of each post.

Size:
The size of the posts shall be classified based on their diameter at the groundline and their length. The groundline diameter shall be specified by diameter in 1/8–in. (3) breaks. The length shall be specified in 1–in. (25) 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 minimum groundline diameter of the PP posts shall be 8 5/8–in. (219) with an upper limit of 9 1/8–in. (232).

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 1 1/4–in. (32) at any point. Posts shall be free from reverse bends.

Splits, Checks, and Shakes:
Splits or ring shakes are not permitted in the top 2/3 of the post. Checks are not permitted in the top 2/3 of the post if wider than 1/3 of the diameter if dry and wider than 3/8 of the diameter if not dry. Splits exceeding the diameter in length are not permitted in the bottom 1/3 of the post. A shake or check is permitted in the bottom 1/3 of the post as long as it is not wider than 1/2 of the butt diameter. (Note – check size is determined as the average measured penetration over its length.)

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3 1/2–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 3/4–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 1/4 of the radius.

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

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Midwest Roadside Safety Facility

Ponderosa Pine and Southern Yellow Pine Post Alternatives for U.S. Standards

Bill of Materials and Grading Criteria

SHEET: 3 of 3
DATE: 11/3/2014
DRAWN BY: JEK/KLK/SDB
REV. BY: SKR/RKF
DWG. NAME. PP–SYP–US_R3
SCALE: NONE
UNITS: in.[mm]

Figure 21. Bill of Materials and PP Grading Criteria – Testing in Weak Soil

4.3 Test Results

Results from all four dynamic component tests are discussed in the following sections. The force and displacement data shown in this section were calculated from the SLICE-2 accelerometer unit. Results for all accelerometers used on each test are provided in Appendix B.

4.3.1 Test No. PPW-1

During test no. PPW-1, the bogie impacted the 8.55-in. (217-mm) diameter PP post at a speed of 20.0 mph (32.2 km/h). Upon impact, the post began to rotate through the soil. Post rotation continued until the bogie overrode the post 0.140 ms after impact at a displacement of 31.8 in. (808 mm). The round PP post showed no signs of fracture when examined after the impact event.

Force versus deflection and energy versus deflection curves are shown in Figure 22. Early on, the resistive force quickly increased and reached a peak of 9.9 kips (44.0 kN) at 6.1 in. (155 mm) of deflection. After this peak, the resistive force steadily decreased for the remainder of the impact event. A total of 165.9 kip-in. (18.7 kJ) of energy was absorbed by the post before the bogie overrode the post at 31.8 in. (808 mm). Time-sequential and post-impact photographs are shown in Figure 23.

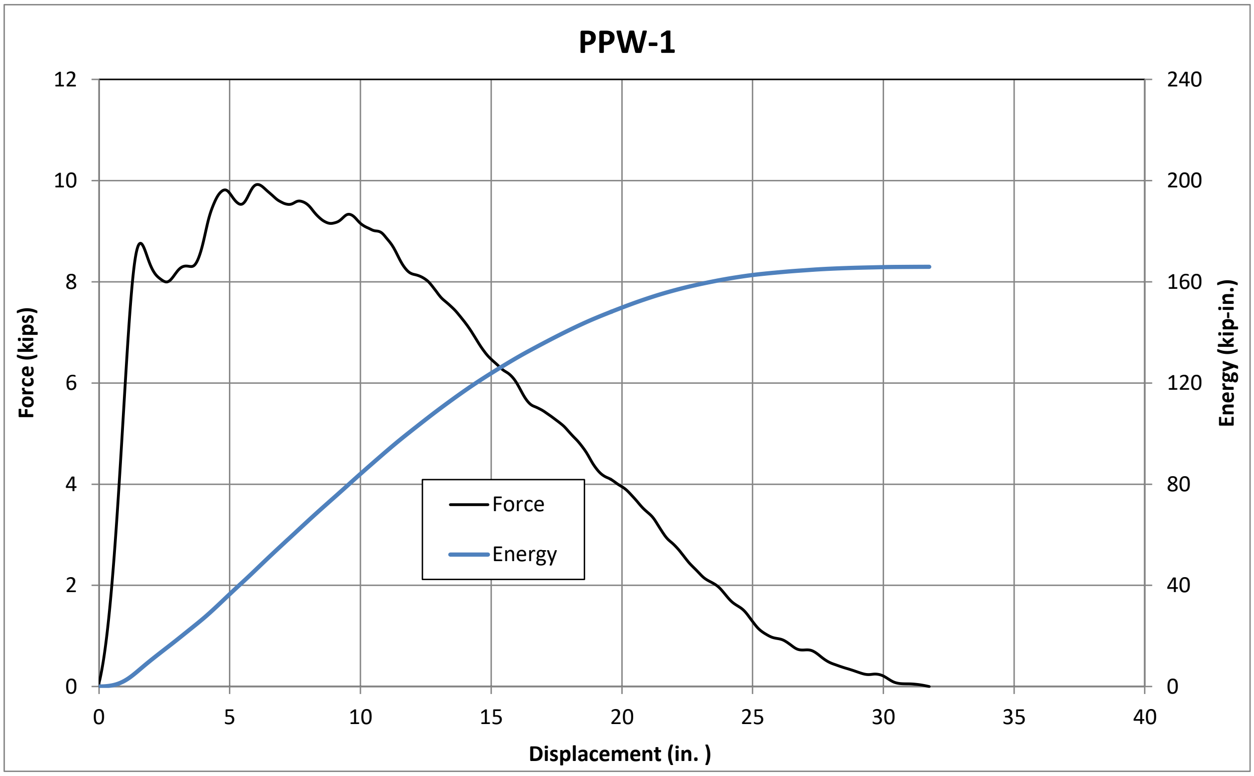
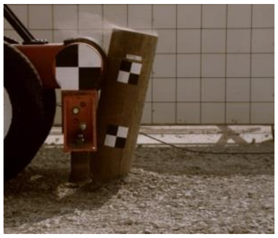


Figure 22. Force vs. Displacement and Energy vs. Displacement, Test No. PPW-1

IMPACT



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0.060 sec

0.090 sec

0.120 sec

0.150 sec

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

4.3.2 Test No. PPW-2

During test no. PPW-2, the bogie impacted the 8.48-in. (215-mm) diameter PP post at a speed of 20.6 mph (33.2 km/h). Upon impact, the post began to rotate through the soil. Post rotation continued until the bogie overrode the post 0.144 ms after impact at a displacement of 36.6 in. (930 mm). The round PP post showed no signs of fracture when examined after the impact event.

Force versus deflection and energy versus deflection curves are shown in Figure 24. Initially, the resistive force quickly increased and reached a peak of 9.8 kips (43.6 kN) at 4.7 in. (119 mm) of deflection. The force was held relatively constant at around 9.0 kips (40.0 kN) through 12 in. (305 mm) of displacement, after which the resistive force steadily decreased for the remainder of the impact event. A total of 180.5 kip-in. (20.4 kJ) of energy was absorbed by the post before the bogie overrode the post at 31.8 in. (808 mm). Time-sequential and post-impact photographs are shown in Figure 25.

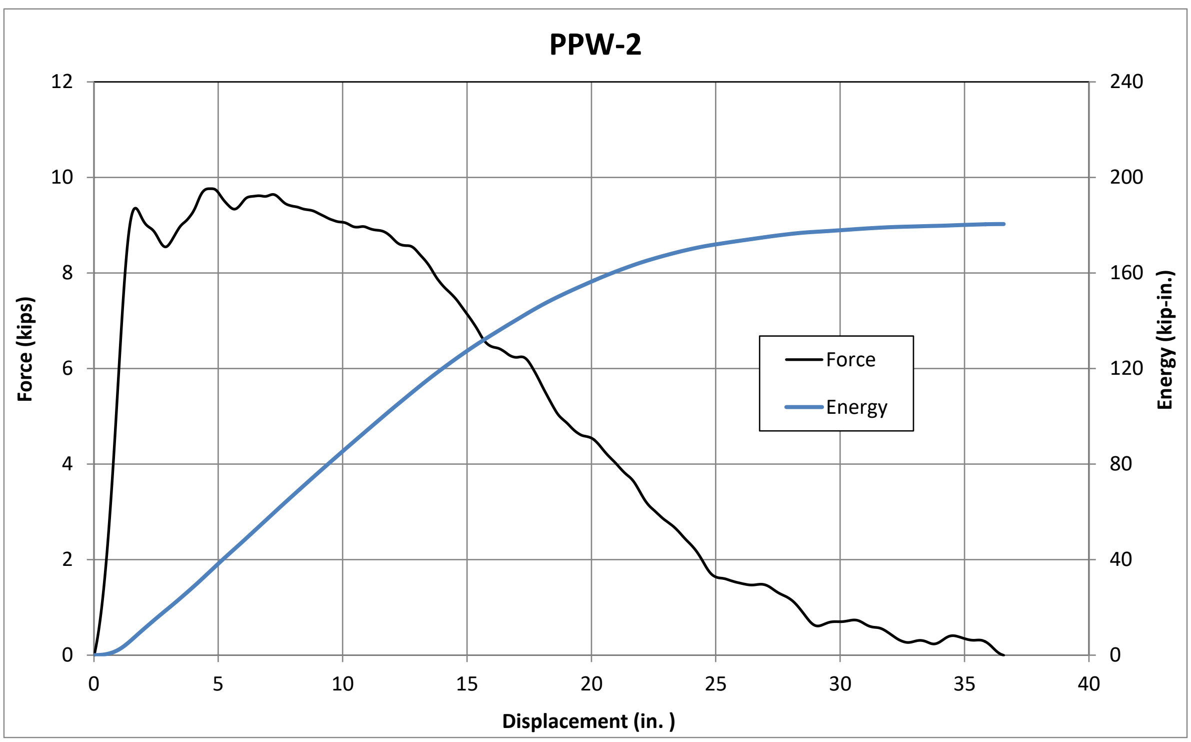
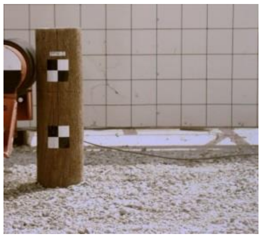


Figure 24. Force vs. Displacement and Energy vs. Displacement, Test No. PPW-2


IMPACT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0.150 sec

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

4.3.3 Test No. PPSYPW-1

During test no. PPSYPW-1, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) SYP post at a speed of 20.1 mph (32.3 km/h). Upon impact, the post began to rotate through the soil. Post rotation continued until the bogie overrode the post 0.160 ms after impact at a displacement of 37.7 in. (958 mm). The rectangular SYP post showed no signs of fracture when examined after the impact event.

Force versus deflection and energy versus deflection curves are shown in Figure 26. Initially, the resistive force increased quickly and reached a peak of 10.4 kips (46.3 kN) at 4.7 in. (119 mm) of deflection. The resistive force was held relatively constant at approximately 9.0 kips (40.0 kN) through 10 in. (254 mm) of displacement, after which the force steadily decreased for the remainder of the impact event. A total of 204.7 kip-in. (23.1 kJ) of energy was absorbed by the post before the bogie overrode the post at 37.7 in. (958 mm). Time-sequential and post-impact photographs are shown in Figure 27.

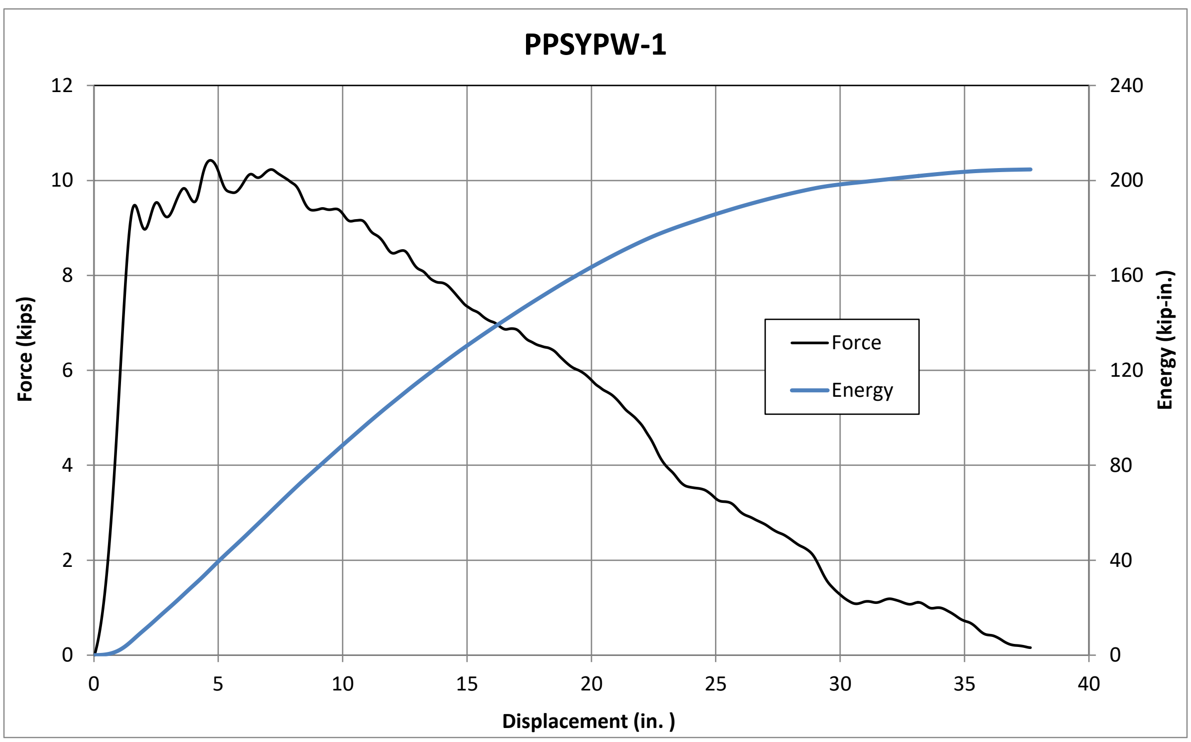

Figure 26. Force vs. Displacement and Energy vs. Displacement, Test No. PPSYPW-1

IMPACT

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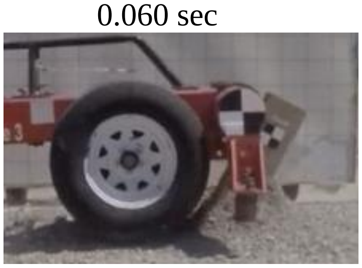

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Figure 27. Time-Sequential and Post-Impact Photographs, Test No. PPSYPW-1

4.3.4 Test No. PPSYPW-2

During test no. PPSYPW-2, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) SYP post at a speed of 20.8 mph (33.5 km/h). Upon impact, the post began to rotate backward. The post continued to rotate backward until it fractured 0.026 seconds after initial impact at a deflection of 8.8 in. (224 mm). Post-test examination revealed the post had fractured approximately 6 in. (152 mm) below the groundline.

Force versus deflection and energy versus deflection curves are shown in Figure 28. After the force rapidly increased to over 8.0 kips (35.6 kN) within the first two inches of displacement, a peak force of 10.1 kips (44.9 kN) was observed at 7.2 in. (183 mm) of deflection. At this point, the post began to fracture, and the resistive force quickly dropped. The energy absorbed by the post was 68.9 kip-in. (7.8 kJ) by the completion of fracture at 8.8 in. (224 mm) of deflection. Time-sequential and post-impact photographs are shown in Figure 29.

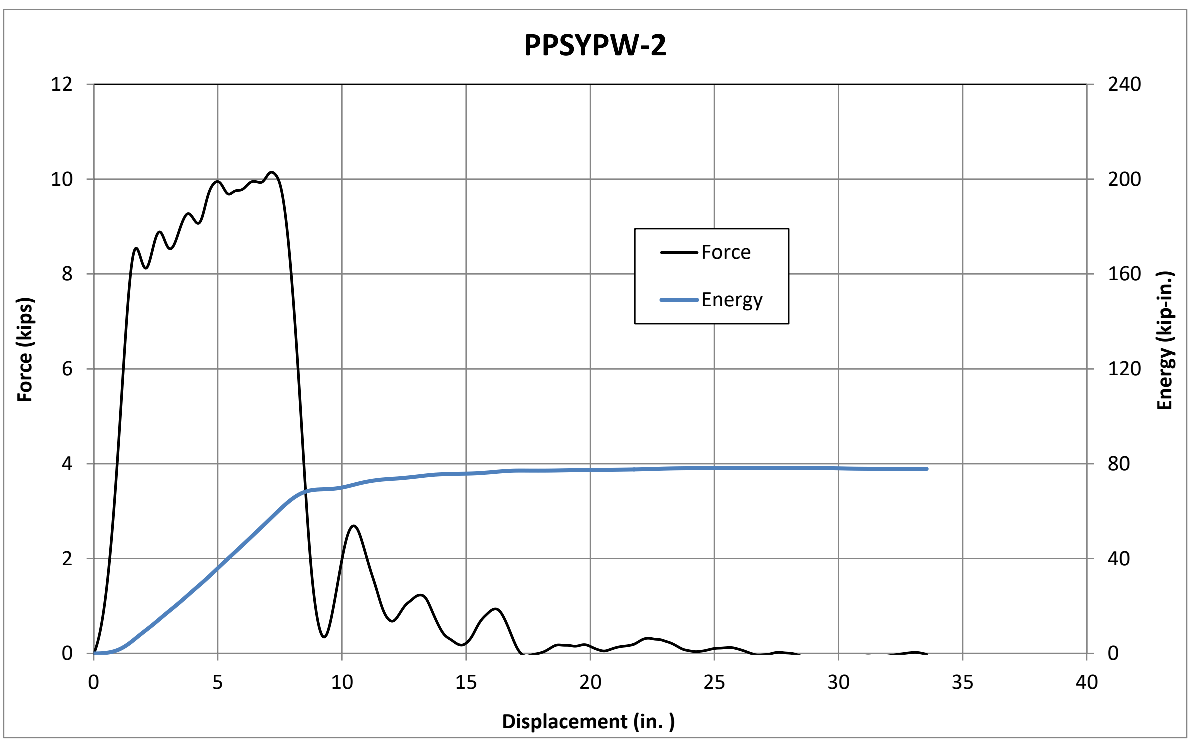

Figure 28. Force vs. Displacement and Energy vs. Displacement, Test No. PPSYPW-2

IMPACT

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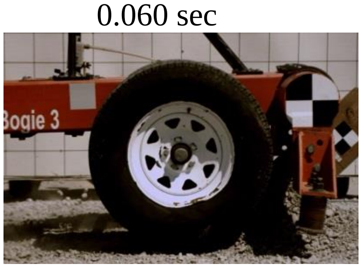
0.060 sec



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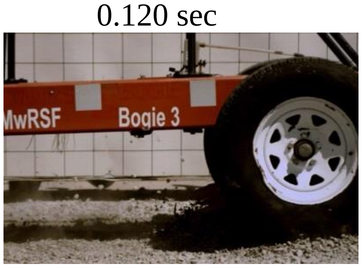

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Figure 29. Time-Sequential and Post-Impact Photographs, Test No. PPSYPW-2

4.4 Discussion

Round 2 of the Phase II component testing consisted of four component tests conducted within less stiff soil, two of these tests on 6-in. x 8-in. (152-mm x 203-mm) SYP posts with 43¼-in. (1,099-mm) embedment depths and two tests on 8⅝-in. (219-mm) diameter PP posts with 36-in. (914-mm) embedment depths. Results from the Round 2 tests are summarized in Table 7. Force versus displacement and energy versus displacement curves are shown in Figures 30 and 31, respectively.

Both PP posts and one SYP post rotated through the soil as desired, while the other SYP post fractured after a peak load of 10.1 kips (44.9 kN). This latter test result provided the lowest peak/fracture load observed from any of the previous SYP posts evaluated in Phase II Round 1 and Phase I of this project [6]. Thus, the post fracture of test no. PPSYPW-4 was attributed to natural variations in timber strength that resulted in a slightly weaker post. Since the rectangular SYP post has long been a standard within the G4(2W) guardrail system, this singular post fracture did not cause concern.

The resistive forces observed for the three posts that rotated through the soil were very similar in terms of magnitude and duration, as shown in Figure 30. Thus, the average forces calculated for the round PP posts were very similar to those of the rectangular SYP posts. As shown in Table 7, the average forces for the PP posts were within 6 percent of the SYP posts through displacements of 5, 10, 15, and 20 in. (127, 254, 381, and 508 mm). Consequently, the average absorbed energies for the two post types were also very similar. Therefore, performance of a 8⅝-in. (219-mm) diameter PP post with a 36-in. (914-mm) embedment depth was deemed approximately equivalent to that of the U.S. standard G4(2W) rectangular SYP post, a 6-in. x 8-

in. (152-mm x 203-mm) post with 43¼-in. (1,099-mm) embedment depth, in terms of soil resistive forces.

Table 7. Bogie Test Results for Weak Soil Testing

Test No.	Timber Species	Post Section in. (mm)	Post Embed. in. (mm)	Impact Velocity mph (km/h)	Peak Force kips (kN)	Average Force kips (kN)				Absorbed Energy kip-in. (kJ)				Failure Mechanism
						@5"	@10"	@15"	@20"	@5"	@10"	@15"	@20"	
PPW-1	PP	Ø 8.55 (Ø 217)	36 (914)	20.1 (32.3)	9.9 (44.0)	7.3 (32.3)	8.4 (37.4)	8.3 (36.7)	7.5 (33.3)	36.3 (4.1)	84.0 (9.5)	123.8 (14.0)	149.8 (16.9)	Rotation in Soil
PPW-2	PP	Ø 8.48 (Ø 215)	36 (914)	20.6 (33.2)	9.8 (43.6)	7.6 (33.8)	8.5 (37.9)	8.5 (37.7)	7.8 (34.8)	38.0 (4.3)	85.1 (9.6)	127.3 (14.4)	156.3 (17.7)	Rotation in Soil
AVERAGE					**9.9 (43.8)**	**7.4 (33.1)**	**8.5 (37.6)**	**8.4 (37.2)**	**7.7 (34.1)**	**37.2 (4.2)**	**84.6 (9.6)**	**125.6 (14.2)**	**153.1 (17.3)**	
PPSYPW-1	SYP	6 x 8 (152x203)	43¼ (1,099)	20.1 (32.3)	10.4 (46.3)	7.8 (34.8)	8.8 (39.2)	8.7 (38.6)	8.2 (36.3)	39.1 (4.4)	88.2 (10.0)	130.3 (14.7)	163.5 (18.5)	Rotation in Soil
PPSYPW-2	SYP	6 x 8 (152x203)	43¼ (1,099)	20.8 (33.5)	10.1 (44.9)	7.2 (31.9)	NA	NA	NA	35.9 (4.1)	NA	NA	NA	Post Fracture
AVERAGE					**10.3 (45.6)**	**7.5 (33.4)**	**8.8 (39.2)**	**8.7 (38.6)**	**8.2 (36.3)**	**37.5 (4.2)**	**88.2 (10.0)**	**130.3 (14.7)**	**163.5 (18.5)**	

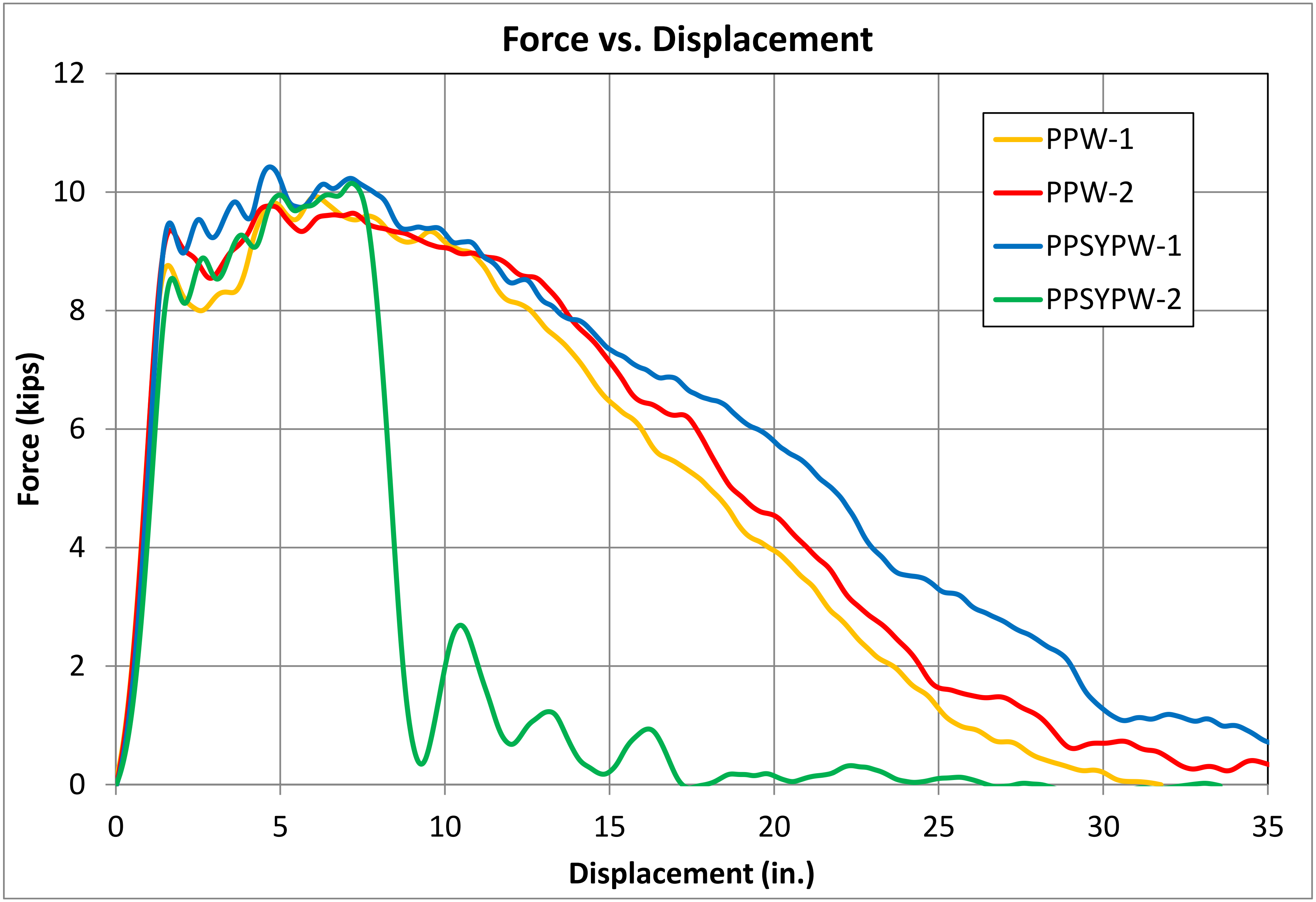

Figure 30. Force vs. Displacement Plot, Round 2 Testing Results - Weak Soil

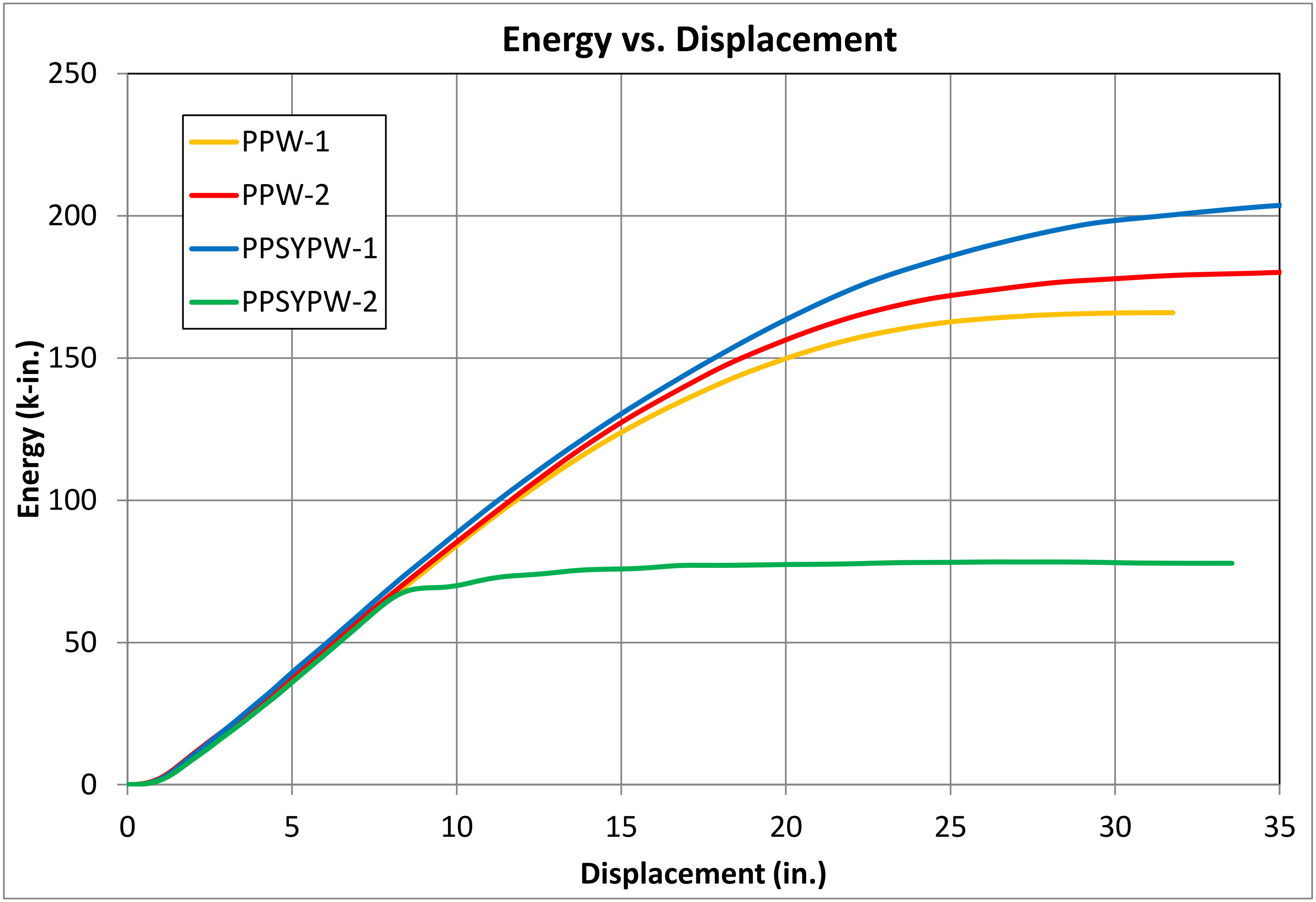

Figure 31. Energy vs. Displacement Plot, Round 2 Testing Results - Weak Soil

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this Phase II research study was to determine the appropriate size and embedment depth for a round PP post to serve as a surrogate for the standard 6-in. x 8-in. x 72-in. long (152-mm x 203-mm x 1,829-mm) SYP post embedded 43¼ in. (1,099 mm) used in U.S. standard W-beam guardrail systems, and 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 [7].

To complete the objective noted above, dynamic component tests were conducted on the standard rectangular SYP posts and round PP posts. Testing was divided into two separate rounds. Round 1 of testing consisted of posts installed in strong soils and evaluated the fracture strength, or capacity, of both types of timber posts. Round 2 was conducted within a less stiff soil to allow increased post rotation and assessment of the soil-resistive forces applied to the different post sections and embedment depths. An 8½-in. (216-mm) diameter and a 35-in. (889-mm) embedment depth were selected for the PP posts based on testing results from the Phase I project [6].

Round 1 of the Phase II component testing consisted of two tests on rectangular SYP posts and three tests on round PP posts. During testing, all five of the posts fractured with only minimal rotation through the strong soil. The results from these tests were combined with the results from the tests conducted on three SYP posts and five round PP posts of similar diameters during the Phase I project. The average peak loads observed for the five rectangular SYP and eight round PP posts were found to be 15.8 kips (70.1 kN) and 15.6 kips (69.2 kN), respectively, as shown previously in Table 5. With less than a 2 percent difference in ultimate strength, the two post sections were deemed to have equivalent strengths. Thus, the recommended minimum groundline diameter selected for a PP post used in U.S. standard G4(2W) guardrail systems was 8⅝ in. (219 mm).

Round 2 of the Phase II component testing consisted of two tests on rectangular SYP posts and two tests on round PP posts conducted within a moderately compacted soil. One of the SYP posts fractured during testing and was later determined to have a strength capacity lower than a typical SYP post. The performances of the three posts that rotated through the soil were very similar in terms of resistive forces. In fact, the average forces and absorbed energies between the two post types were within 6 percent at deflections between 5 in. and 20 in. (127 mm and 508 mm). Therefore, the soil resistances for the two post types were deemed equivalent, and the recommended embedment depth selected for a PP post used in U.S. standard G4(2W) guardrail systems was 36 in. (914 mm).

Based on the test results, an 8⅝-in. (219-mm) groundline diameter PP post with a 36-in. (914-mm) embedment depth was recommended as the surrogate post for the SYP post utilized in U.S. standard G4(2W) guardrail systems. At this time, the research team believes that a fabrication tolerance of minus 0 in. to plus ½ in., or 8⅝ in. to 9⅛ in. (219 mm to 232 mm), would provide a reasonable range for the groundline 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 U.S. standard G4(2W) guardrail systems, as provided in Appendix C. Although not mentioned in this report specifically, the design details and materials specifications for the accompanying Arizona standard guardrail system are also provided in Appendix C. 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 C. 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.

6 REFERENCES

1. *Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment*, U.S. Department of Interior and U.S. Department of Agriculture, August 2001.

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4. Paun, D. and Jackson, G., *Potential for Expanding Small-Diameter Timber Market Assessing Use of Wood Posts in Highway Applications*, General Technical Report FPL-GTR-120, Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, 2000.

5. Hascall, J.A., Faller, R.K., Reid, J.D., Sicking, D.L., and Kretschmann, D.E., *Investigating the Use of Small-Diameter Softwood as Guardrail Posts (Dynamic Test Results)*, Final Report to the Forest Products Laboratory – U.S. Department of Agriculture, MwRSF Research Report No. TRP-03-179-07, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 28, 2007.

6. Price, C.W., Faller, R.K., Rosenbaugh, S.K., Lechtenberg, K.A., and Winkelbauer, B.J., *Phase I Ponderosa Pine Round Post Equivalency Study*, Final Report to the Forest Products Laboratory and Arizona Log & Timberworks, MwRSF Research Report No. TRP-03-287-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 22, 2013.

7. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.

8. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, New York, July, 2007.

9. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

7 APPENDICES

Appendix A. Material Specifications

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 A-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 A-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 VICE PRESIDENT
TRIO FOREST PRODUCTS INC

Figure A-3. Post Material Certification for SYP Posts

Appendix B. Bogie Test Results

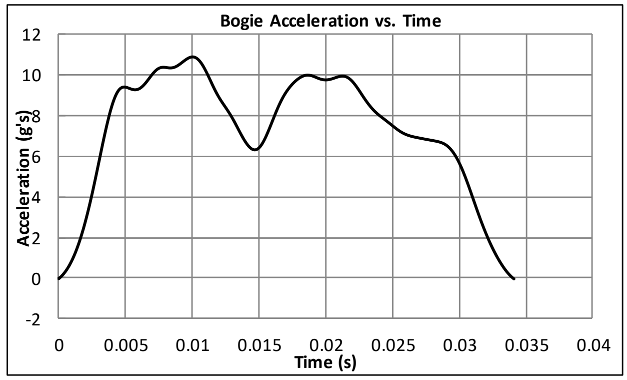
Test results were determined from the recorded data for each accelerometer in each dynamic bogie test and shown in this appendix. Summary sheets include acceleration, velocity, and deflection vs. time plots as well as force vs. deflection and energy vs. deflection plots.

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Southern Yellow Pine Wood Post	
Test Number:	SYPUS-1	
Test Date:	20-Aug-2013	
Failure Type:	Post Rotated in Soil and Fractured Below Groundline	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	71.75 in.	182.2 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	5062013	
Moisture Content:	3.554	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	23.17 mph (34 fps)	10.36 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1632.6 lbs	740.5 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS8	

Test Results Summary		
Max. Deflection:	12.2	in.
Peak Force:	17.7	k
Initial Linear Stiffness:	8.2	k/in.
Total Energy:	146.0	k-in.



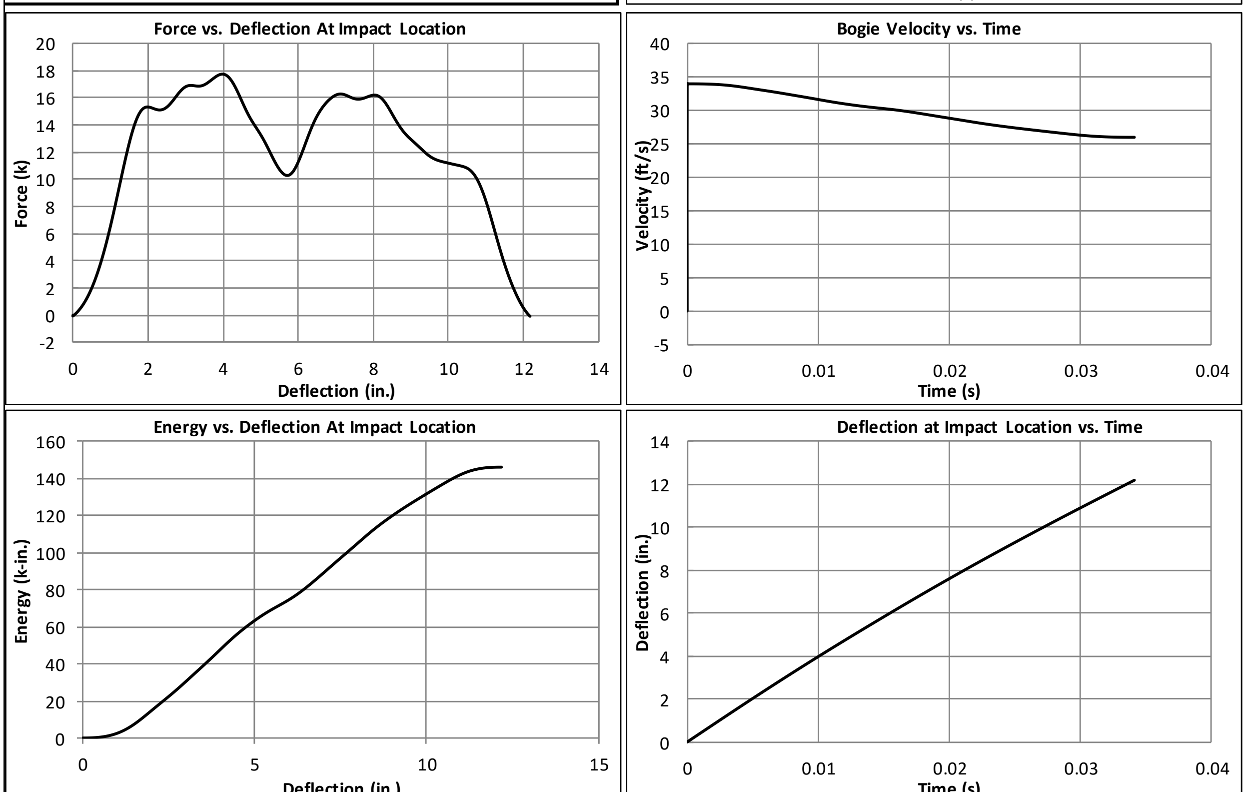


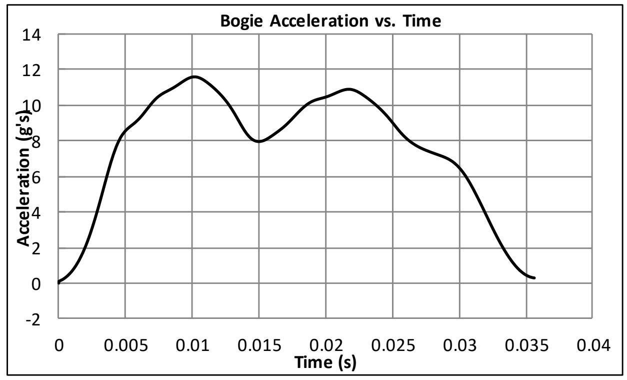
Figure B-1. Results of Test No. SYPUS-1 (DTS)

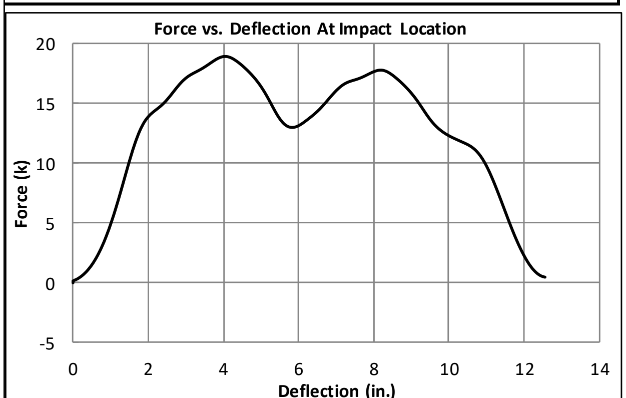
MIDWEST ROADSIDE SAFETY FACILITY

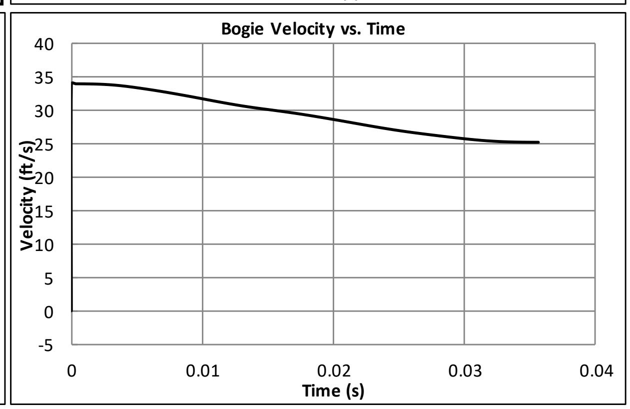
Bogie Test Summary

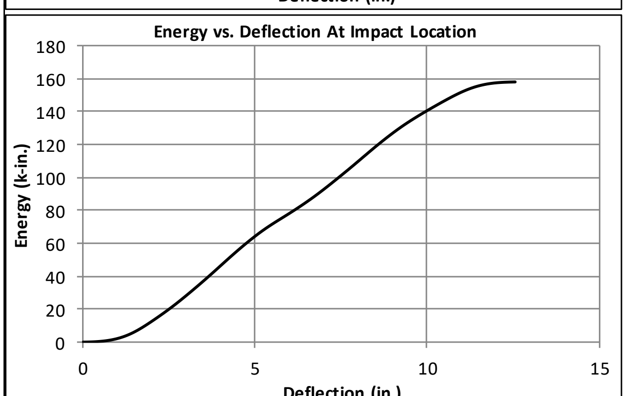
Test Information	Southern Yellow Pine Wood Post	
Test Number:	SYPUS-1	
Test Date:	20-Aug-2013	
Failure Type:	Post Rotated in Soil and Fractured Below Groundline	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	71.75 in.	182.2 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	5062013	
Moisture Content:	3.554	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	23.17 mph (34 fps)	10.36 m/s
Impact Height:	21.65 in.	55 cm
Bogie Mass:	1632.6 lbs	740.5 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS8	

Test Results Summary		
Max. Deflection:	12.6	in.
Peak Force:	18.9	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	158.0	k-in.









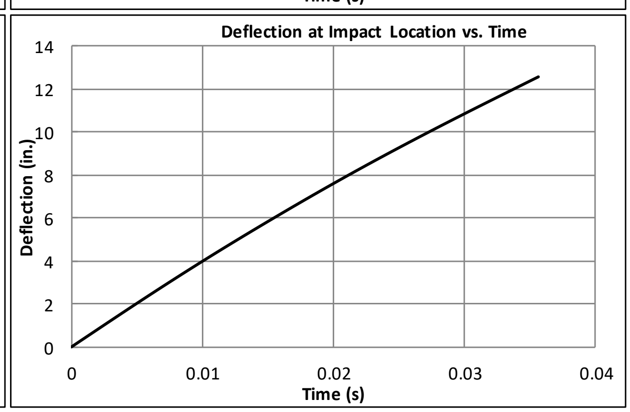


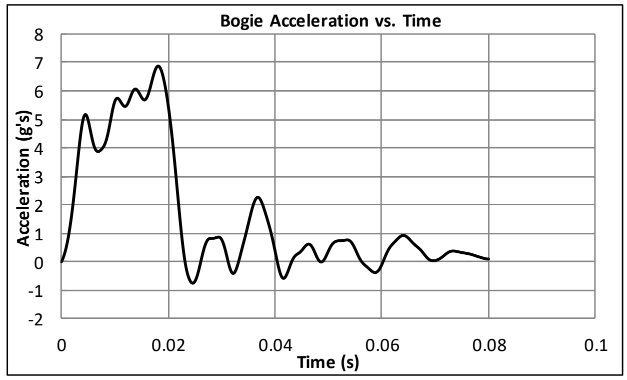
Figure B-2. Results of Test No. SYPUS-1 (EDR-3)

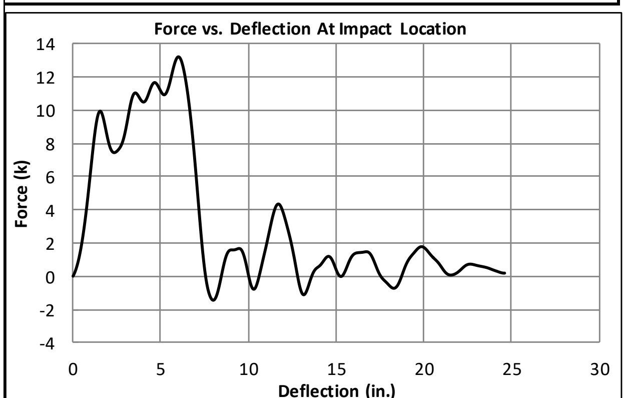
MIDWEST ROADSIDE SAFETY FACILITY

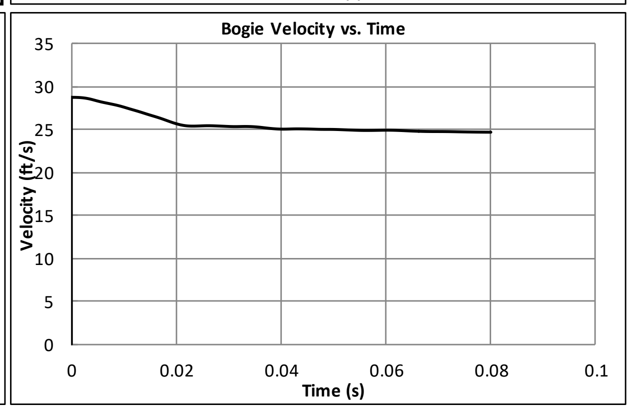
Bogie Test Summary

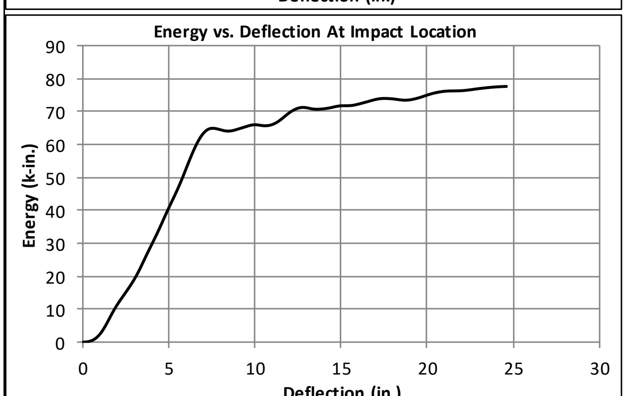
Test Information	Dynamic Bogie Test	
Test Number:	SYPUS-2	
Test Date:	13-Sep-2013	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood	
Post Size:	6 in. x 8 in.	15 cm x 20 cm
Post Length:	72.25 in.	183.5 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	41339	
Moisture Content:	NA	
Compaction Method:	H.E. - 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.6 mph (28.7 fps)	8.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1921 lbs	871.4 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-8 Perpendicular - 140"	

Test Results Summary		
Max. Deflection:	7.5	in.
Peak Force:	13.2	k
Initial Linear Stiffness:	6.4	k/in.
Total Energy:	64.9	k-in.









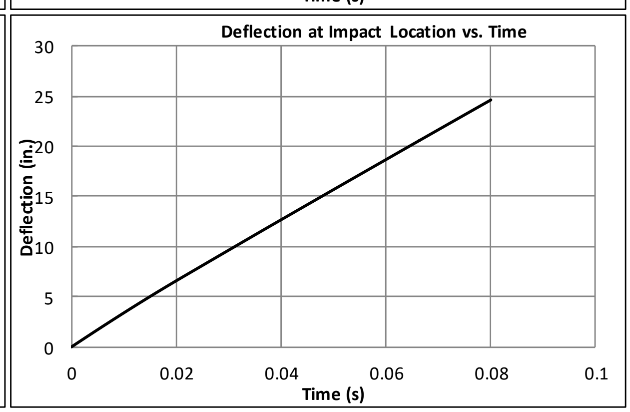


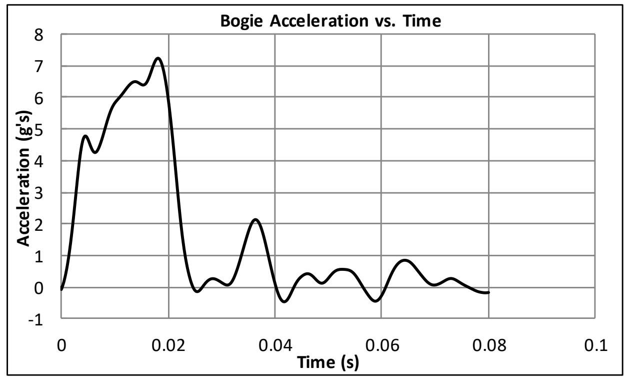
Figure B-3. Results of Test No. SYPUS-2 (DTS)

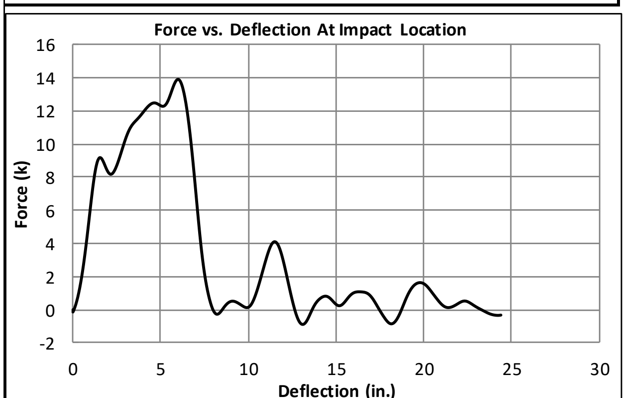
MIDWEST ROADSIDE SAFETY FACILITY

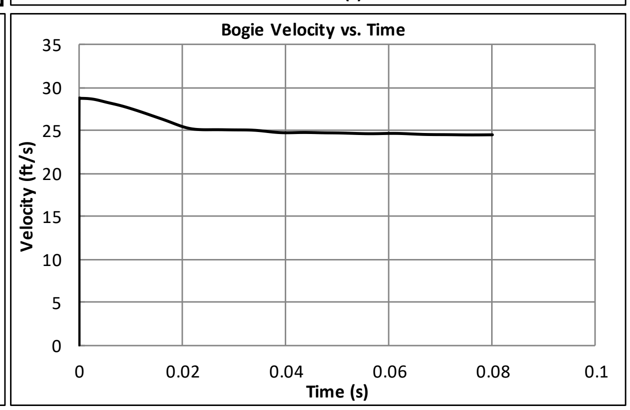
Bogie Test Summary

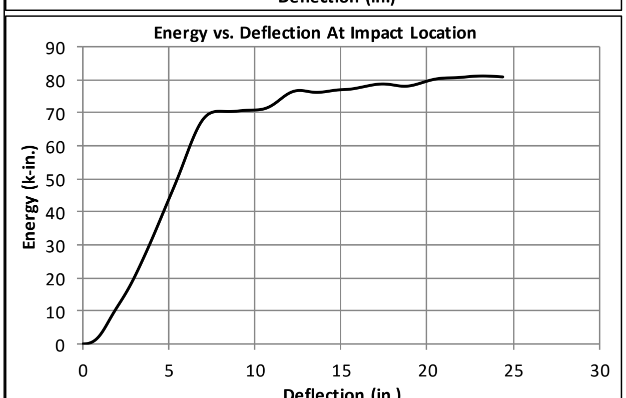
Test Information	Dynamic Bogie Test	
Test Number:	SYPUS-2	
Test Date:	13-Sep-2013	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood	
Post Size:	6 in. x 8 in.	15 cm x 20 cm
Post Length:	72.25 in.	183.5 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	3/6/2013	
Moisture Content:	NA	
Compaction Method:	H.E. - 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.6 mph (28.7 fps)	8.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1921 lbs	871.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-8 Perpendicular - 140"	

Test Results Summary		
Max. Deflection:	8.0	in.
Peak Force:	13.9	k
Initial Linear Stiffness:	6.1	k/in.
Total Energy:	70.5	k-in.









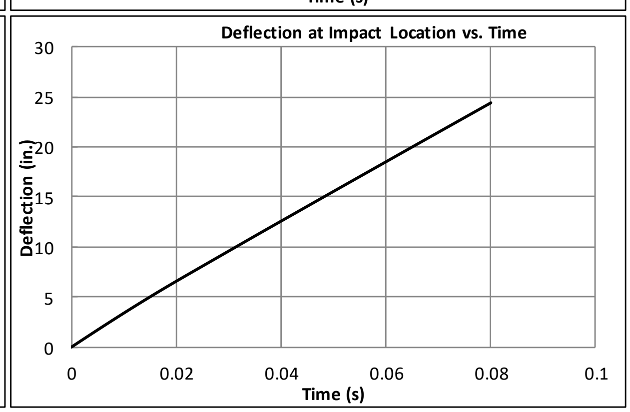


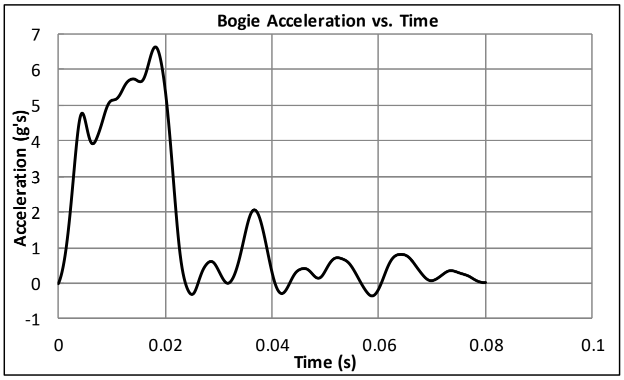
Figure B-4. Results of Test No. SYPUS-2 (EDR-3)

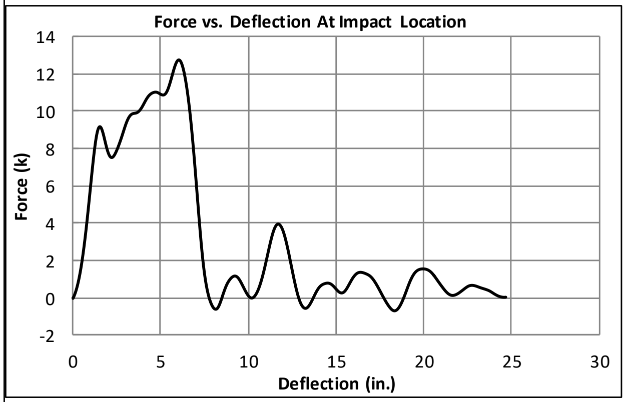
MIDWEST ROADSIDE SAFETY FACILITY

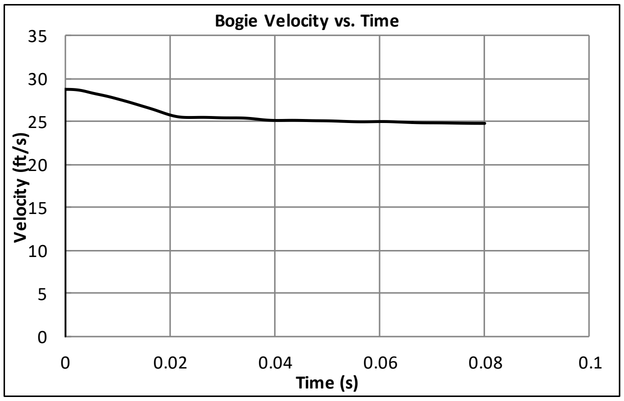
Bogie Test Summary

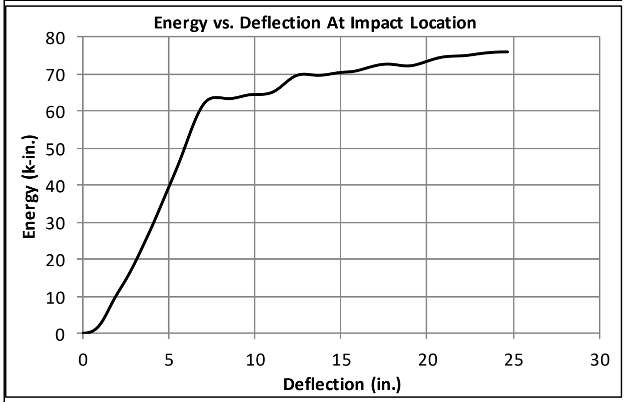
Test Information	Dynamic Bogie Test	
Test Number:	SYPUS-2	
Test Date:	13-Sep-2013	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	Wood	
Post Size:	6 in. x 8 in.	15 cm x 20 cm
Post Length:	72.25 in.	183.5 cm
Embedment Depth:	43.25 in.	109.9 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	41339	
Moisture Content:	NA	
Compaction Method:	H.E. - 8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.6 mph (28.7 fps)	8.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1921 lbs	871.4 kg
Data Acquired		
Acceleration Data:	SLICE-1	
Camera Data:	AOS-8 Perpendicular - 140"	

Test Results Summary		
Max. Deflection:	7.7	in.
Peak Force:	12.7	k
Initial Linear Stiffness:	5.9	k/in.
Total Energy:	63.6	k-in.









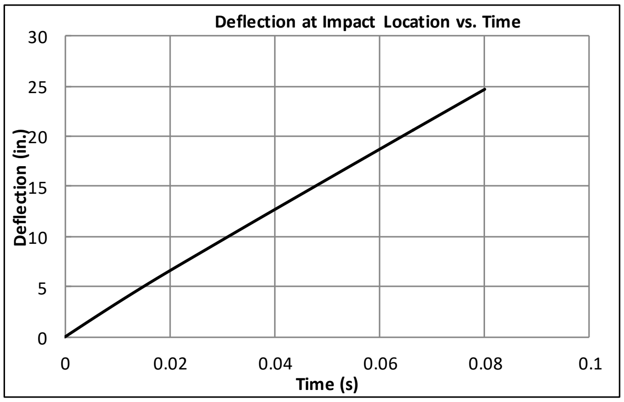


Figure B-5. Results of Test No. SYPUS-2 (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. Post
Test Number:	PPUS-1
Test Date:	5/30/2014
Failure Type:	Post Fracture

Post Properties

Post Type:	Pondersoa Pine - Round
Post Size:	GL - 8.594" Dia. CR - 8.675" Dia.
Post Length:	65"
Embedment Depth:	36"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	4.12% @ 15" 3.92% @ 30"
Compaction Method:	H.E. - 8

Bogie Properties

Impact Velocity:	21.58 mph	(31.65 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1928 lb	

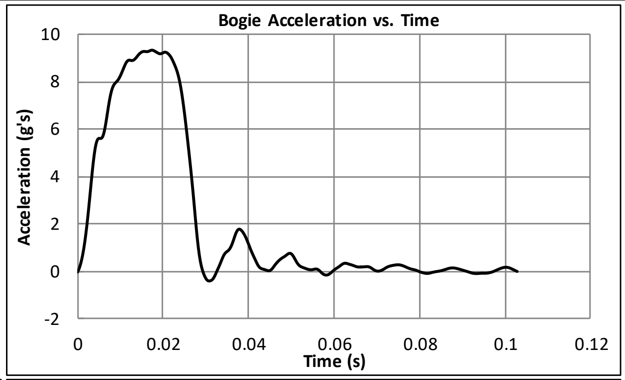
Data Acquired

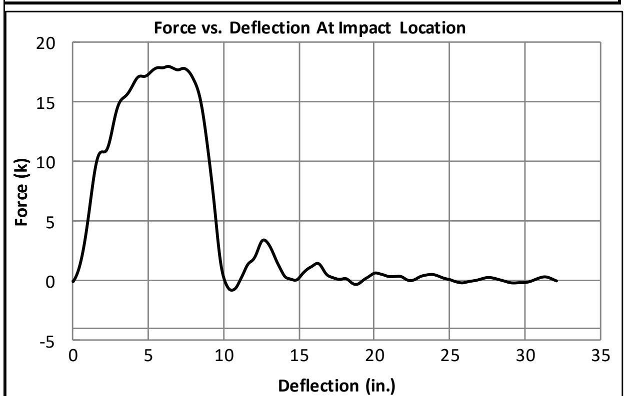
Accelerometer:	SLICE-2
Camera Data:	AOS-8 @ 175"

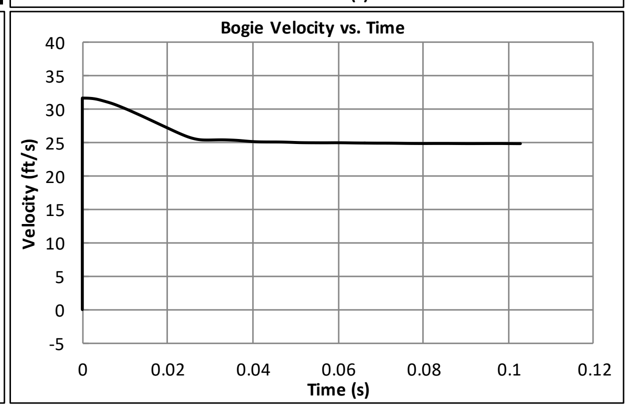
Test Results Summary

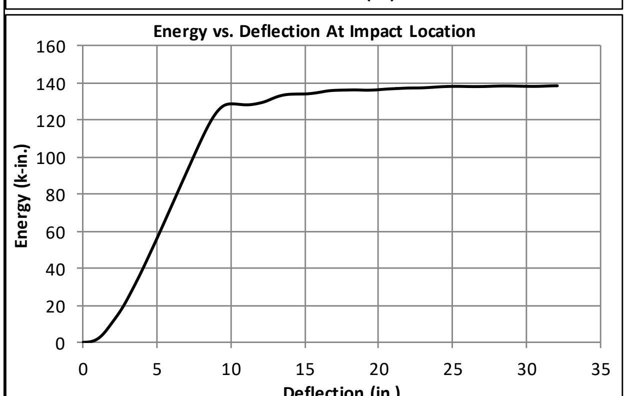
Event Duration:	0.0294	sec
Max. Deflection:	10.1	in.
Peak Force:	18.0	k
Initial Linear Stiffness:	4.9	k/in.
Total Energy:	128.6	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	11.10	12.86	NA	NA
Energy (k-in.)	55.5	128.6	NA	NA









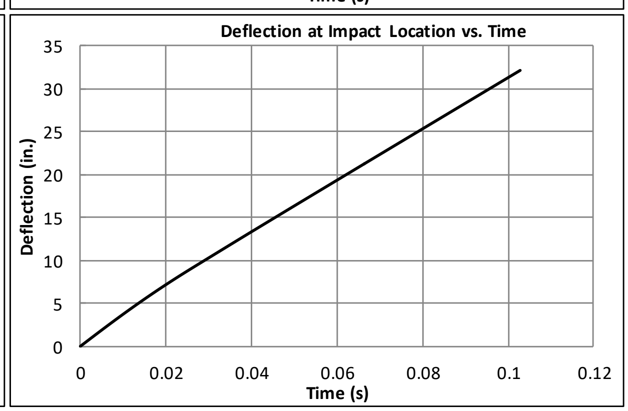


Figure B-6. Results of Test No. PPUS-1 (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. Post
Test Number:	PPUS-2
Test Date:	6/10/2014
Failure Type:	Post Fracture

Post Properties

Post Type:	Pondersoa Pine - Round
Post Size:	GL- 8.594" Dia. CR- 8.594" Dia.
Post Length:	65"
Embedment Depth:	36"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	.
Compaction Method:	H.E. - 8

Bogie Properties

Impact Velocity:	19.03 mph	(27.91 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1928 lb	

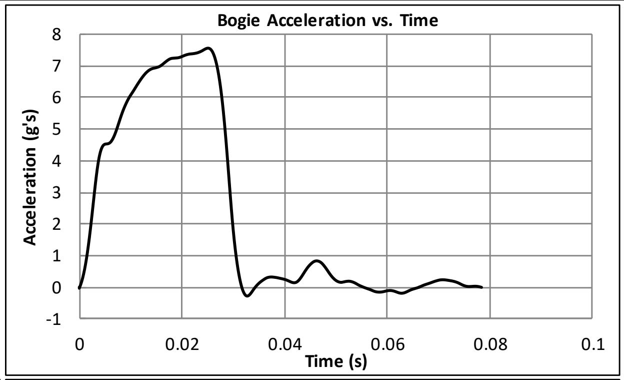
Data Acquired

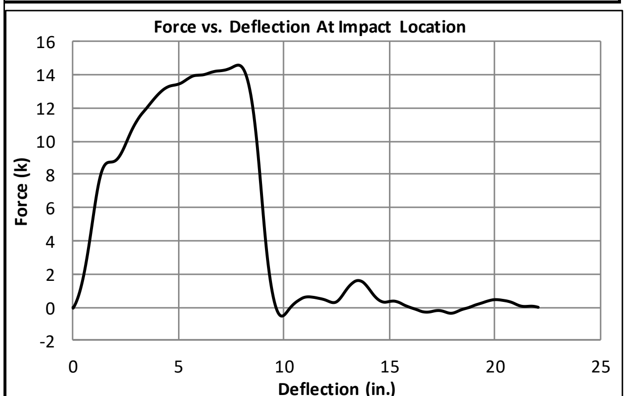
Accelerometer:	SLICE-2
Camera Data:	AOS-8 @ 238"

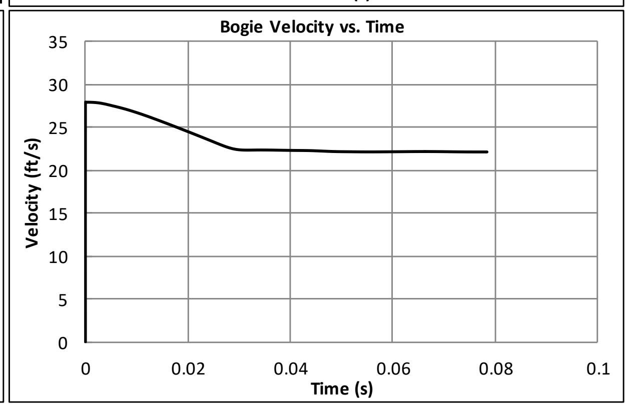
Test Results Summary

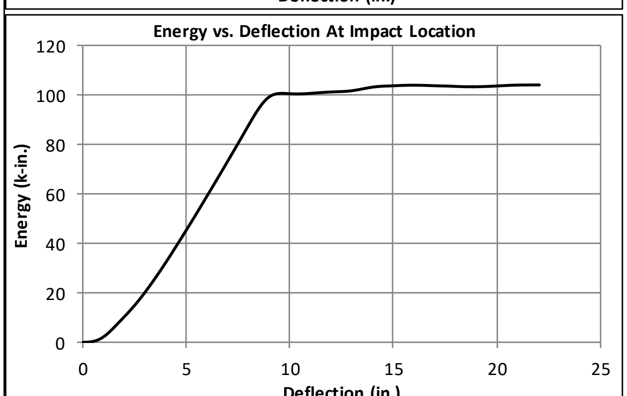
Event Duration:	0.0317	sec
Max. Deflection:	9.6	in.
Peak Force:	14.6	k
Initial Linear Stiffness:	6.0	k/in.
Total Energy:	100.7	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	9.07	10.05	NA	NA
Energy (k-in.)	45.3	100.5	NA	NA









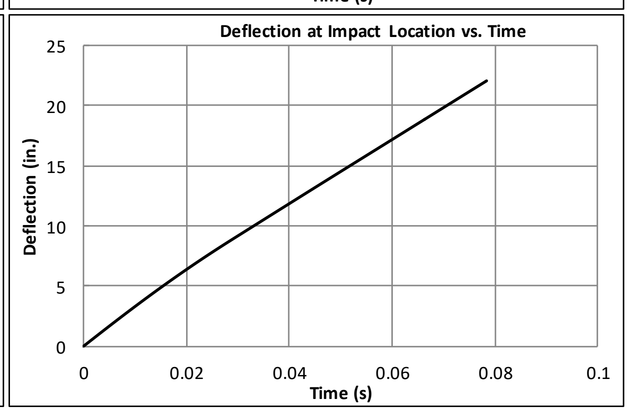


Figure B-7. Results of Test No. PPUS-2 (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. Post
Test Number:	PPUS-3
Test Date:	6/10/2014
Failure Type:	Post Fracture

Post Properties

Post Type:	Pondersoa Pine - Round
Post Size:	GL- 8.555" Dia. CR- 8.594" Dia.
Post Length:	65"
Embedment Depth:	36"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	.
Compaction Method:	H.E. - 8

Bogie Properties

Impact Velocity:	19.48 mph	(28.57 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1928 lb	

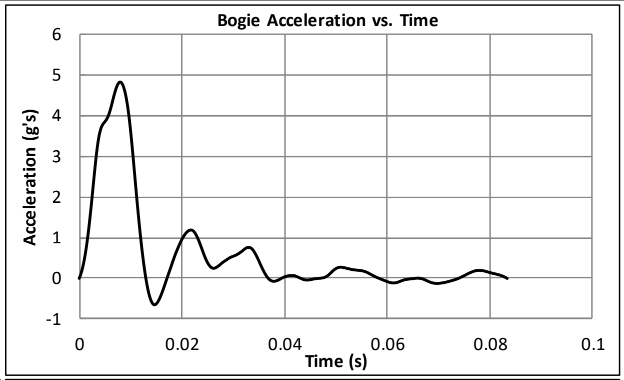
Data Acquired

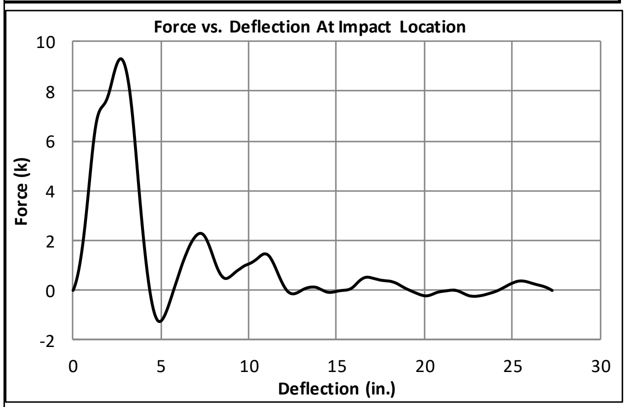
Accelerometer:	SLICE-2
Camera Data:	AOS-8 @ 239"

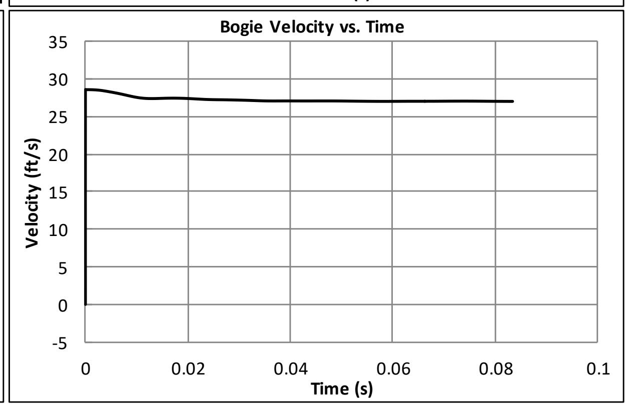
Test Results Summary

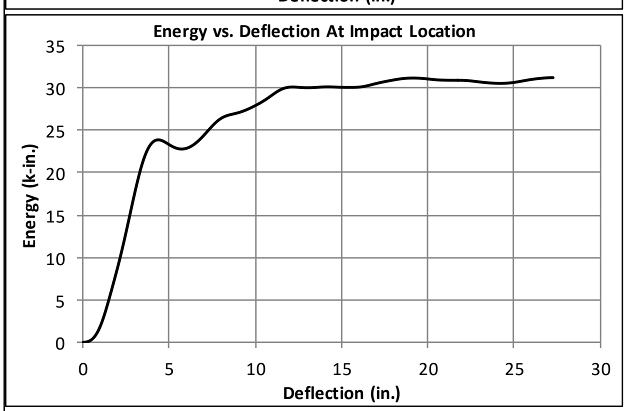
Event Duration:	0.0130	sec
Max. Deflection:	4.4	in.
Peak Force:	9.3	k
Initial Linear Stiffness:	3.4	k/in.
Total Energy:	23.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.66	NA	NA	NA
Energy (k-in.)	23.3	NA	NA	NA









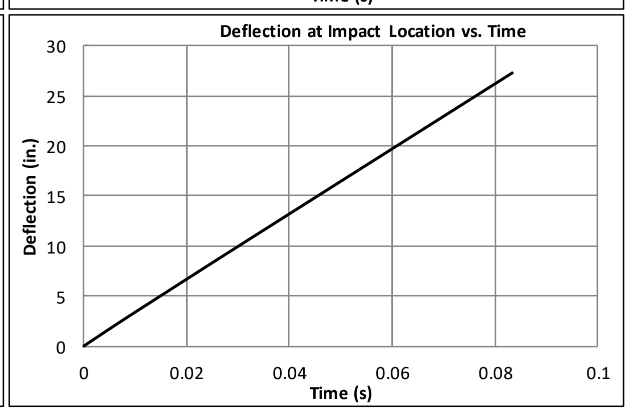


Figure B-8. Results of Test No. PPUS-3 (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. post in weak soil
Test Number:	PPW-1
Test Date:	8/20/2014
Failure Type:	Post Rotation

Post Properties

Post Type:	Round Ponderosa Pine
Post Size:	8.55" diameter
Post Length:	65"
Embedment Depth:	36"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	-
Compaction Method:	Low Energy - 8" lifts

Bogie Properties

Impact Velocity:	20.05 mph	(29.41 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1783 lb	

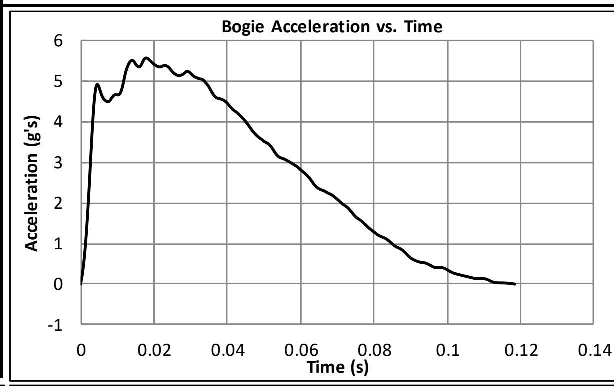
Data Acquired

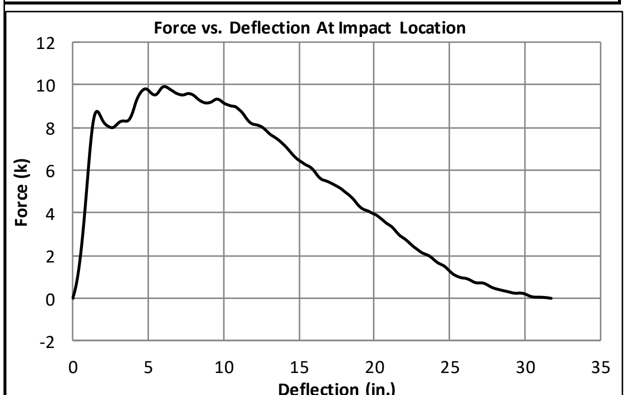
Accelerometer:	SLICE-2
Camera Data:	AOS-8 / GP-5 @ 242"

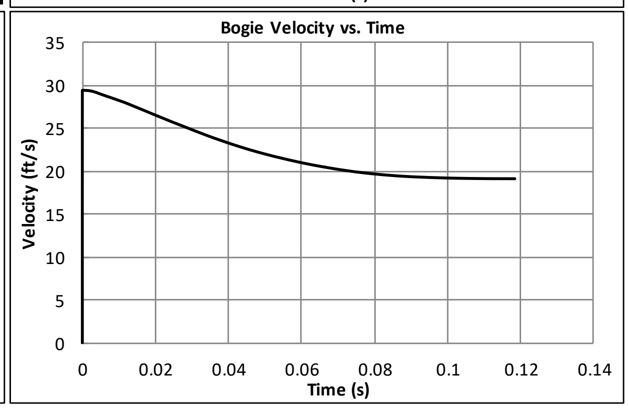
Test Results Summary

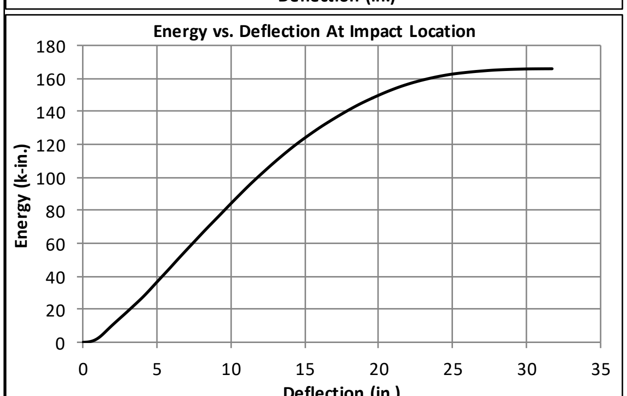
Event Duration:	0.1184	sec
Max. Deflection:	31.8	in.
Peak Force:	9.9	k
Initial Linear Stiffness:	1.6	k/in.
Total Energy:	165.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	7.26	8.40	8.25	7.49
Energy (k-in.)	36.3	84.0	123.8	149.8









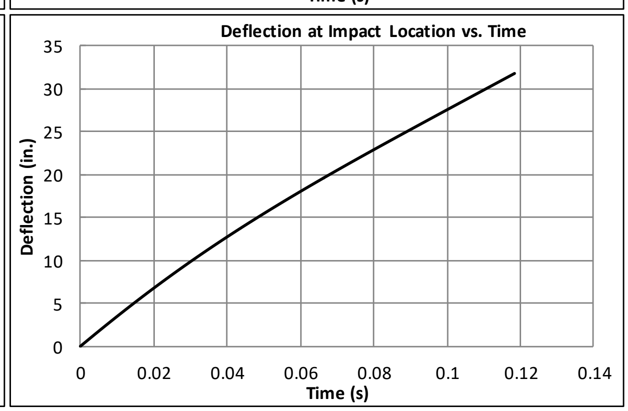


Figure B-9. Results of Test No. PPW-1 (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. post in weak soil
Test Number:	PPW-2
Test Date:	8/20/2014
Failure Type:	Post Rotation

Post Properties

Post Type:	Round Ponderosa Pine
Post Size:	8.475" diameter
Post Length:	65"
Embedment Depth:	36"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	-
Compaction Method:	Low Energy - 8" lifts

Bogie Properties

Impact Velocity:	20.6 mph	(30.21 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1783 lb	

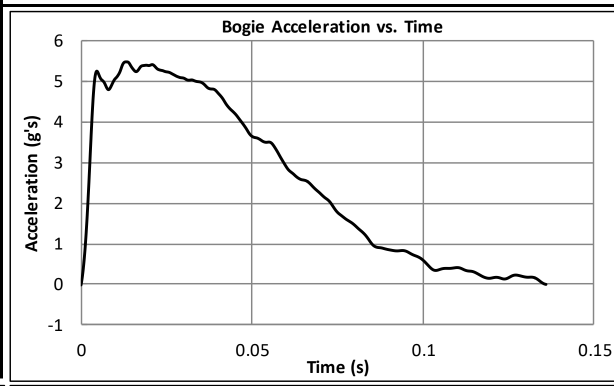
Data Acquired

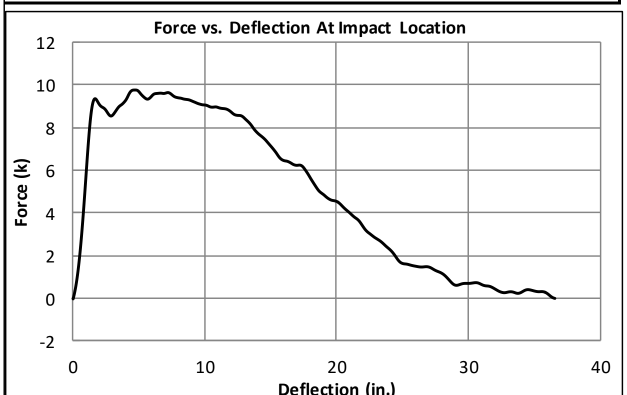
Accelerometer:	SLICE-2
Camera Data:	AOS-8 / GP-5 @ 242"

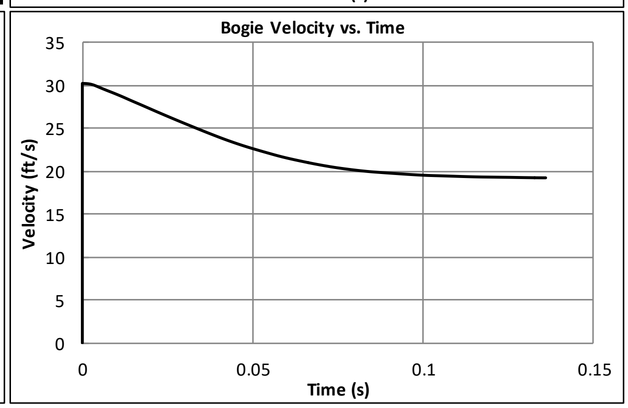
Test Results Summary

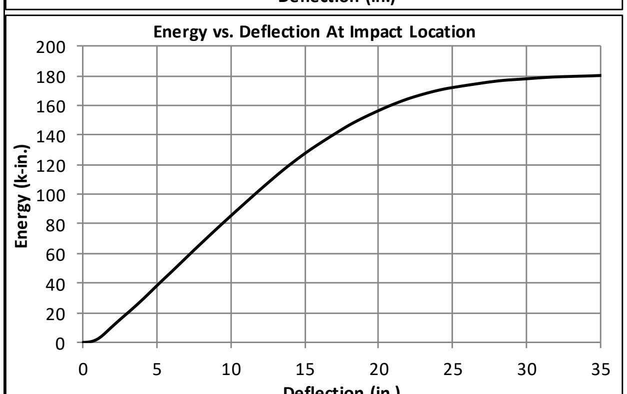
Event Duration:	0.1359	sec
Max. Deflection:	36.6	in.
Peak Force:	9.8	k
Initial Linear Stiffness:	2.1	k/in.
Total Energy:	180.5	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	7.60	8.51	8.48	7.82
Energy (k-in.)	38.0	85.1	127.3	156.3









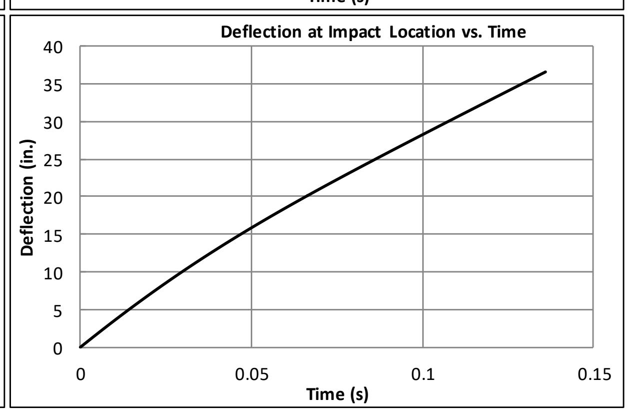


Figure B-10. Results of Test No. PPW-2 (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. post in weak soil
Test Number:	PPSYPW-1
Test Date:	8/20/2014
Failure Type:	Post Rotation

Post Properties

Post Type:	Rectangular SYP
Post Size:	6" x 8"
Post Length:	72"
Embedment Depth:	43.25"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	-
Compaction Method:	Low Energy - 8" lifts

Bogie Properties

Impact Velocity:	20.05 mph	(29.41 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1783 lb	

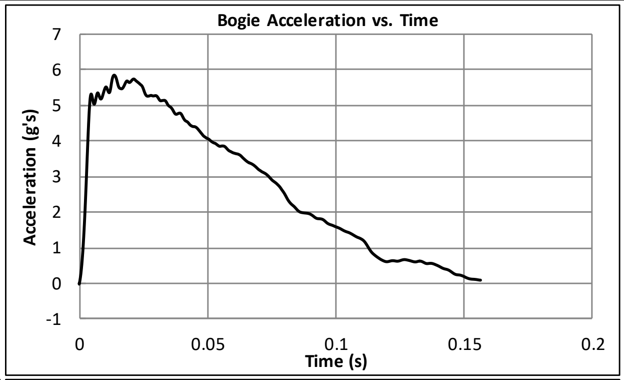
Data Acquired

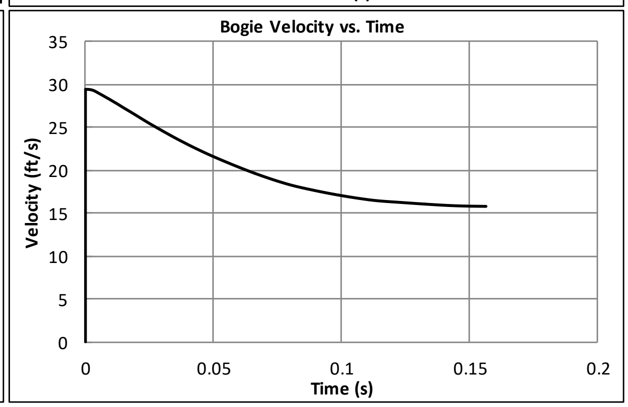
Accelerometer:	SLICE-2
Camera Data:	AOS-8 / GP-5 @ 242"

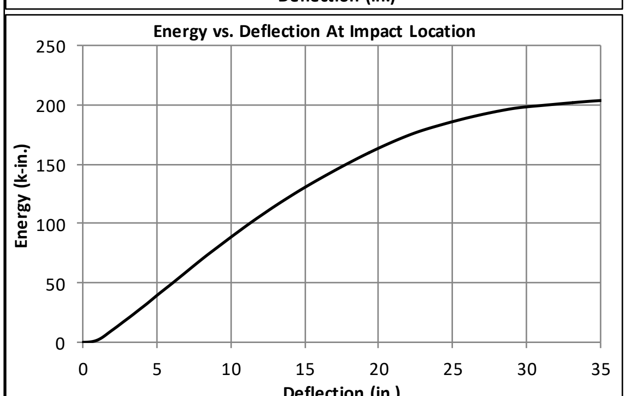
Test Results Summary

Event Duration:	0.1564	sec
Max. Deflection:	37.7	in.
Peak Force:	10.4	k
Initial Linear Stiffness:	2.2	k/in.
Total Energy:	204.7	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	7.83	8.82	8.68	8.17
Energy (k-in.)	39.1	88.2	130.3	163.5







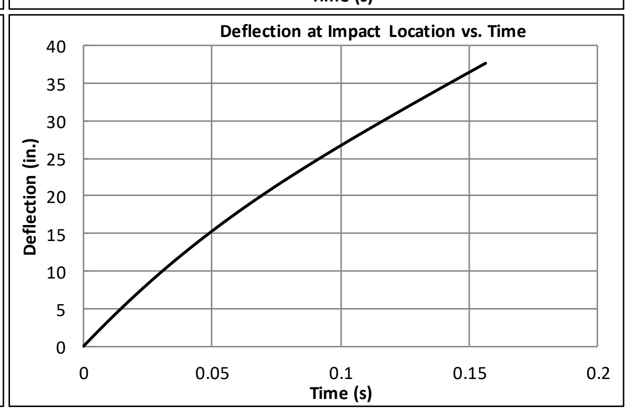


Figure B-11. Results of Test No. PPSYPW-1 (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	Bogie vs. post in weak soil
Test Number:	PPSYPW-2
Test Date:	8/20/2014
Failure Type:	Post Fracture

Post Properties

Post Type:	Rectangular SYP
Post Size:	6" x 8"
Post Length:	72"
Embedment Depth:	43.25"
Orientation:	NA

Soil Properties

Gradation:	9/6/2013
Moisture Content:	-
Compaction Method:	Low Energy - 8" lifts

Bogie Properties

Impact Velocity:	20.75 mph	(30.43 ft/s)
Impact Height:	21.65"	
Bogie Mass:	1783 lb	

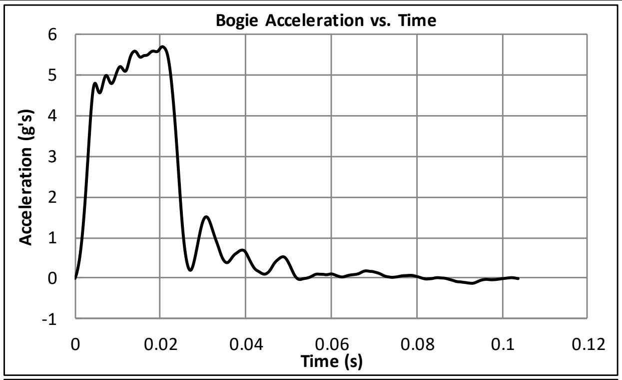
Data Acquired

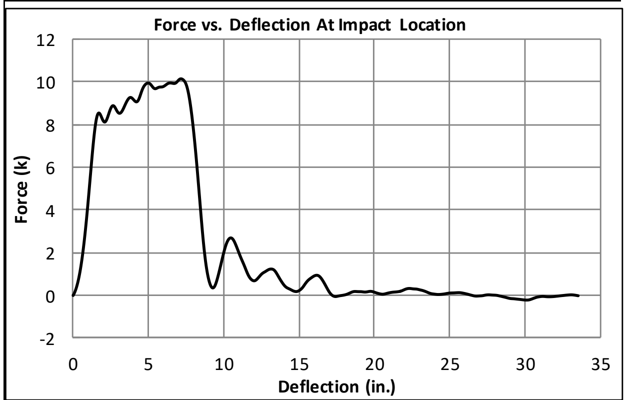
Accelerometer:	SLICE-2
Camera Data:	AOS-8 / GP-5 @ 242"

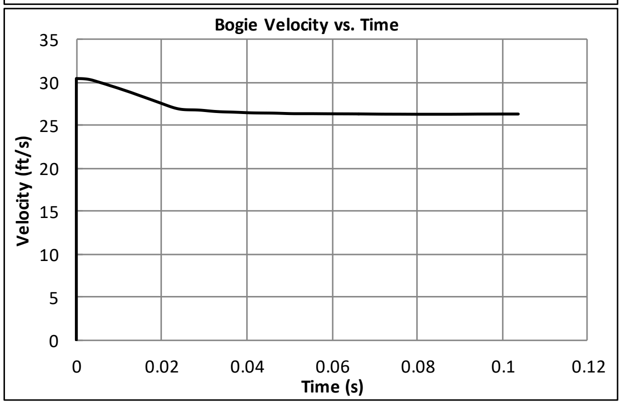
Test Results Summary

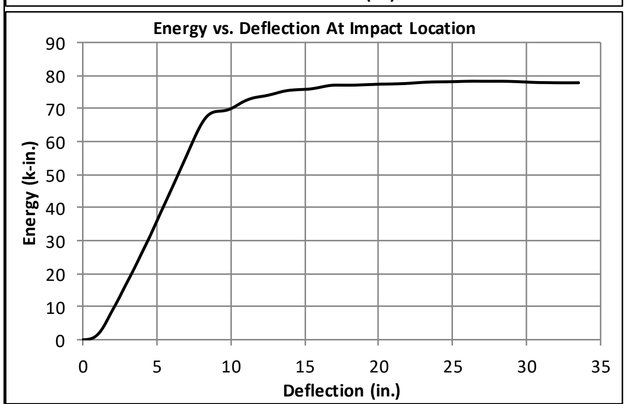
Event Duration:	0.0256	sec
Max. Deflection:	8.8	in.
Peak Force:	10.1	k
Initial Linear Stiffness:	1.4	k/in.
Total Energy:	68.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	7.17	NA	NA	NA
Energy (k-in.)	35.9	NA	NA	NA









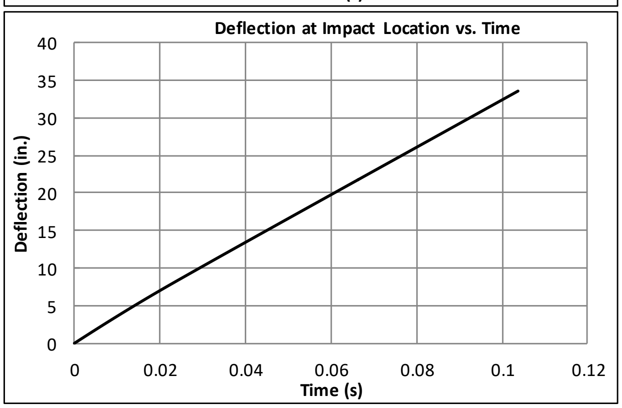


Figure B-12. Results of Test No. PPSYPW-2 (SLICE-2)

Appendix C. Design Details of the G4(2W) Guardrail System with Round PP Posts

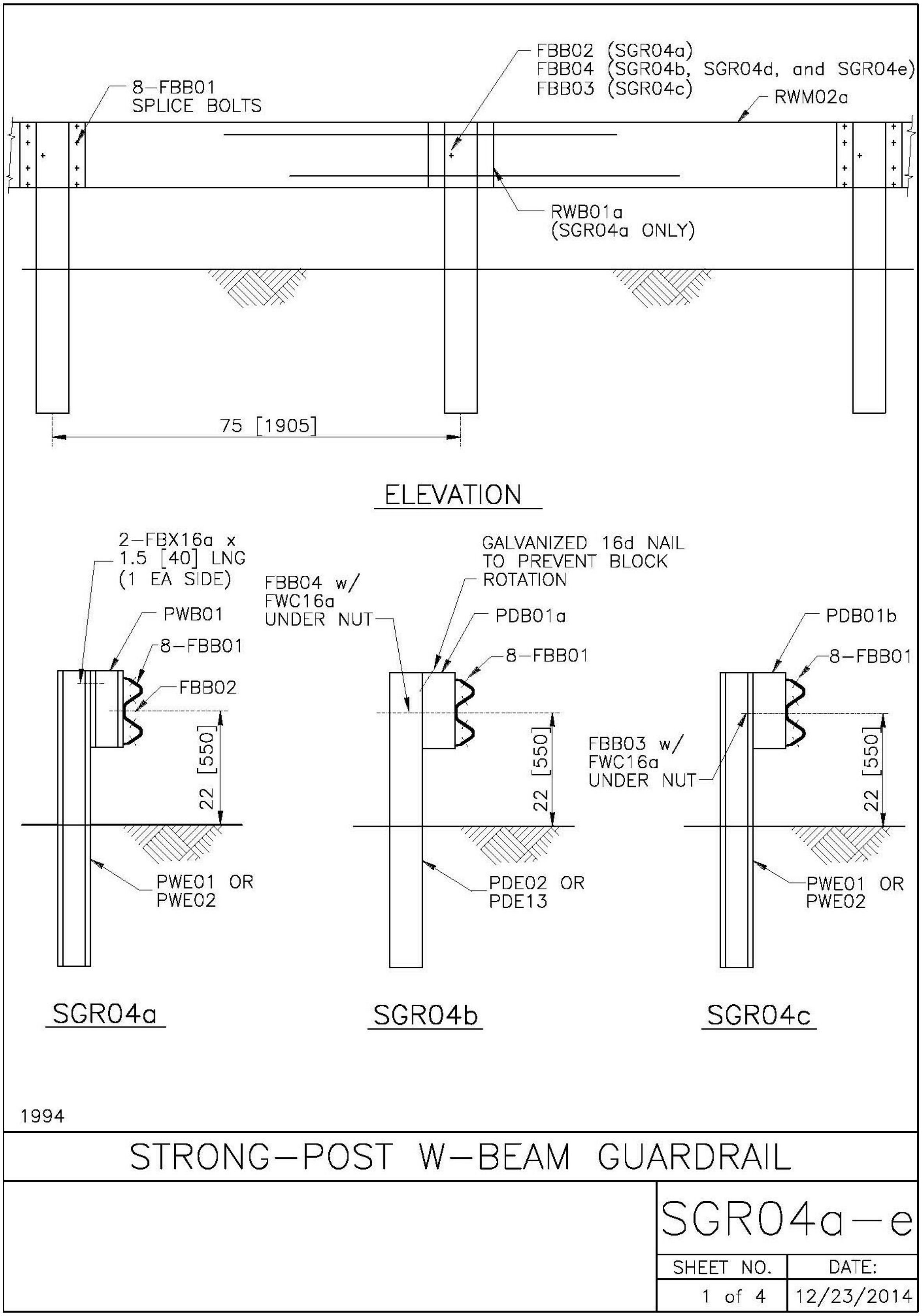


Figure C-1. G4(2W) Guardrail System for Use with Round Posts, Sheet 1

INTENDED USE

Strong-post W-beam guardrails should be used in locations where a maximum dynamic deflection of 36 inches [900 mm] or less is acceptable. W-beam guardrails should be anchored and terminated using a suitable end treatment. SGR-04a (steel posts) with steel blockouts is a Test Level 2 barrier. SGR-04b (wood posts) with wood, steel or plastic blockouts is a Test Level 3 barrier; SGR-04c (steel posts) with wood or plastic blockouts is a Test Level 3 barrier; SGR-04d (round wood posts) with wood blockouts is a Test Level 3 barrier; SGR-04e (round wood posts) with wood blockouts is a Test Level 3 barrier.

COMPONENTS

Unit length = 150 inches [3810 mm]

	Designator	Component	System	Number
	FBB01	Splice bolt and nut	a-e	8
	FBB02	Guardrail-post bolt and nut	a	2
	FBB03	Guardrail-post bolt and nut	c	2
	FBB04	Guardrail-post bolt and nut	b,d,e	2
	FBX16a	Post blockout bolt (1.5 inches [40 mm]) and nut	a	4
	FWC16a	Round washer	b-e	2
	PDB01a	Timber post blockout	b	2
	PDB01b	Timber post blockout	c	2
	PDB23	Round timber post blockout	e	2
	PDB24	Round timber post blockout	d	2
	PDE02	Timber post	b	2
or	PDE13	Timber post	b	2
	PDE21	Round timber post	e	2
	PDE22	Round timber post	d	2
	PWB01	Steel post blockout	a	2
	PWE01	Steel post	a,b	2
or	PWE02	Steel post	a,b	2
	RWB01a	W-beam backup plate	a	1
	RWM02a	W-beam rail	a-e	1

APPROVALS

FHWA Acceptance Letter B-64, 2/14/00.

STRONG-POST W-BEAM GUARDRAIL

SGR04a-e

SHEET NO.	DATE
2 of 4	12/23/2014

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

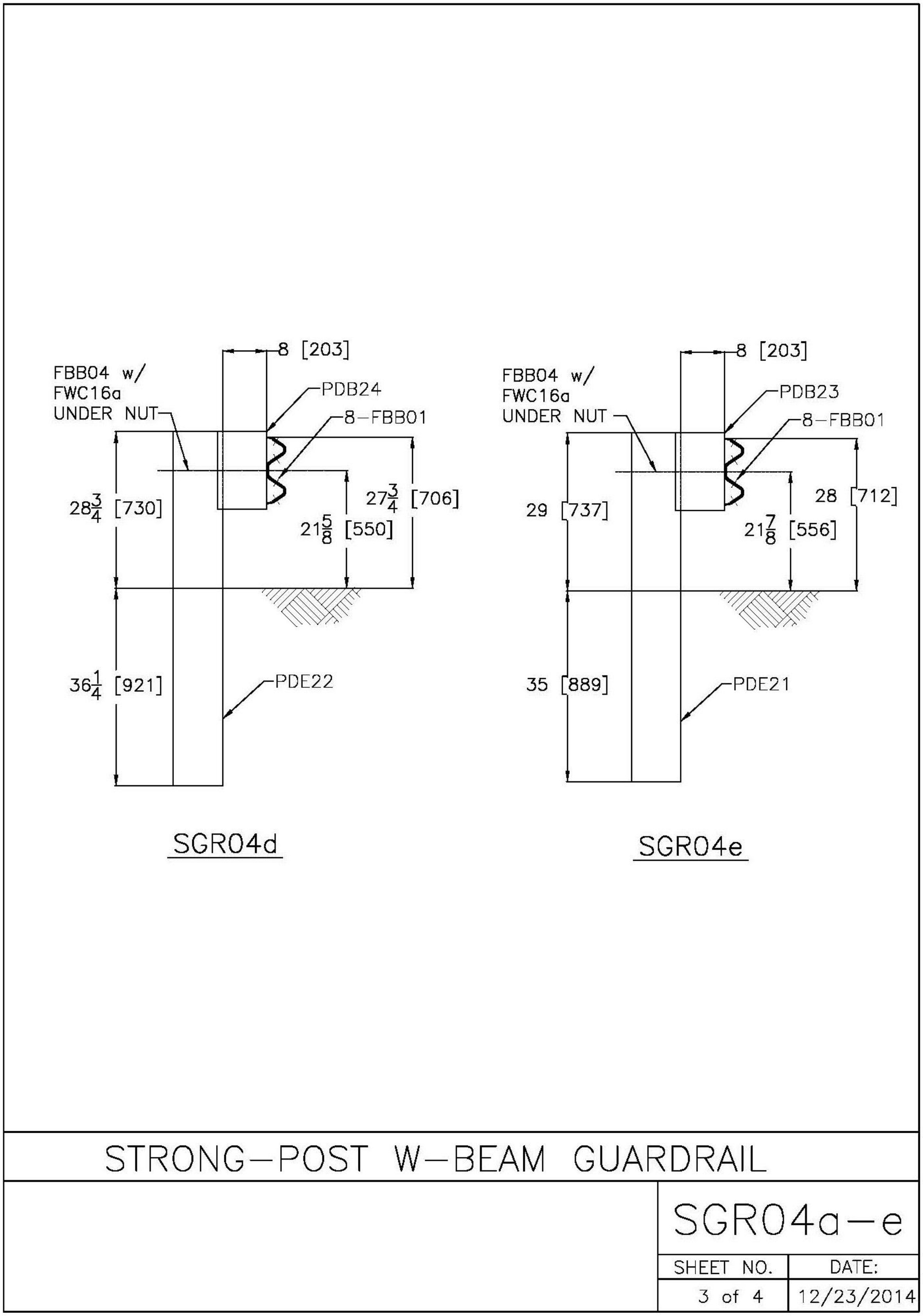


Figure C-3. G4(2W) Guardrail System for Use with Round Posts, Sheet 3

REFERENCES

M.E. Bronstad, J.E. Michie and J.D. Mayer, Jr., *Performance of Longitudinal Traffic Barriers*, National Cooperative Highway Research Program Report Number 289, Transportation Research Board, June, 1987.

C.E. Buth, W.L. Campise, L.I. Griffin, M.L. Love, and D.L. Sicking, *Performance Limits of Longitudinal Barriers*, Federal Highway Administration, Report No. FHWA-RD-86-153 (vol. 1), Washington, D.C., May 1986.

R.L. Stoughton, R.L. Stoker, E.F. Nordlin, *Dynamic Tests of Metal Beam Guardrail*, Transportation Research Record, Transportation Research Board, Washington, D.C., 1975.

Price, C.W., Faller, R.K., Rosenbaugh, S.K., Lechtenberg, K.A., and Winkelbauer, B.J. *Phase I Ponderosa Pine Round-Post Equivalency Study,* Final Report to Forest Products Laboratory U.S. Department of Agriculture – Forest Service and Arizona Log & Timberworks, Transportation Research Report No. TRP-03-287-13, Project No. 12-DG-11111169-033, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, November 22, 2013.

Rosenbaugh, S.K., Faller, R.K., Winkelbauer, B.J., and Schmidt, T.L. *Phase II Ponderosa Pine Round-Post Equivalency Study,* Final Report to Forest Products Laboratory U.S. Department of Agriculture – Forest Service and Arizona Log & Timberworks, Transportation Research Report No. TRP-03-315-14, Project No. 13-JV-11111133-035, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, In Progress.

CONTACT INFORMATION

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STRONG-POST W-BEAM GUARDRAIL

SGR04a-e	
SHEET NO.	DATE
4 of 4	12/23/2014

Figure C-4. G4(2W) Guardrail System for Use with Round Posts, Sheet 4

Designator	System	Wood Type	Minimum Groundline Diameter, Dg	Maximum Groundline Diameter, Dg	Length, L	Post Height, H
PDE21	SGR04e	Ponderosa Pine	8 1/2" [216]	9" [229]	64" [1626]	29" [737]
PDE22	SGR04d	Ponderosa Pine	8 5/8" [219]	9 1/8" [232]	65" [1651]	28 3/4" [730]

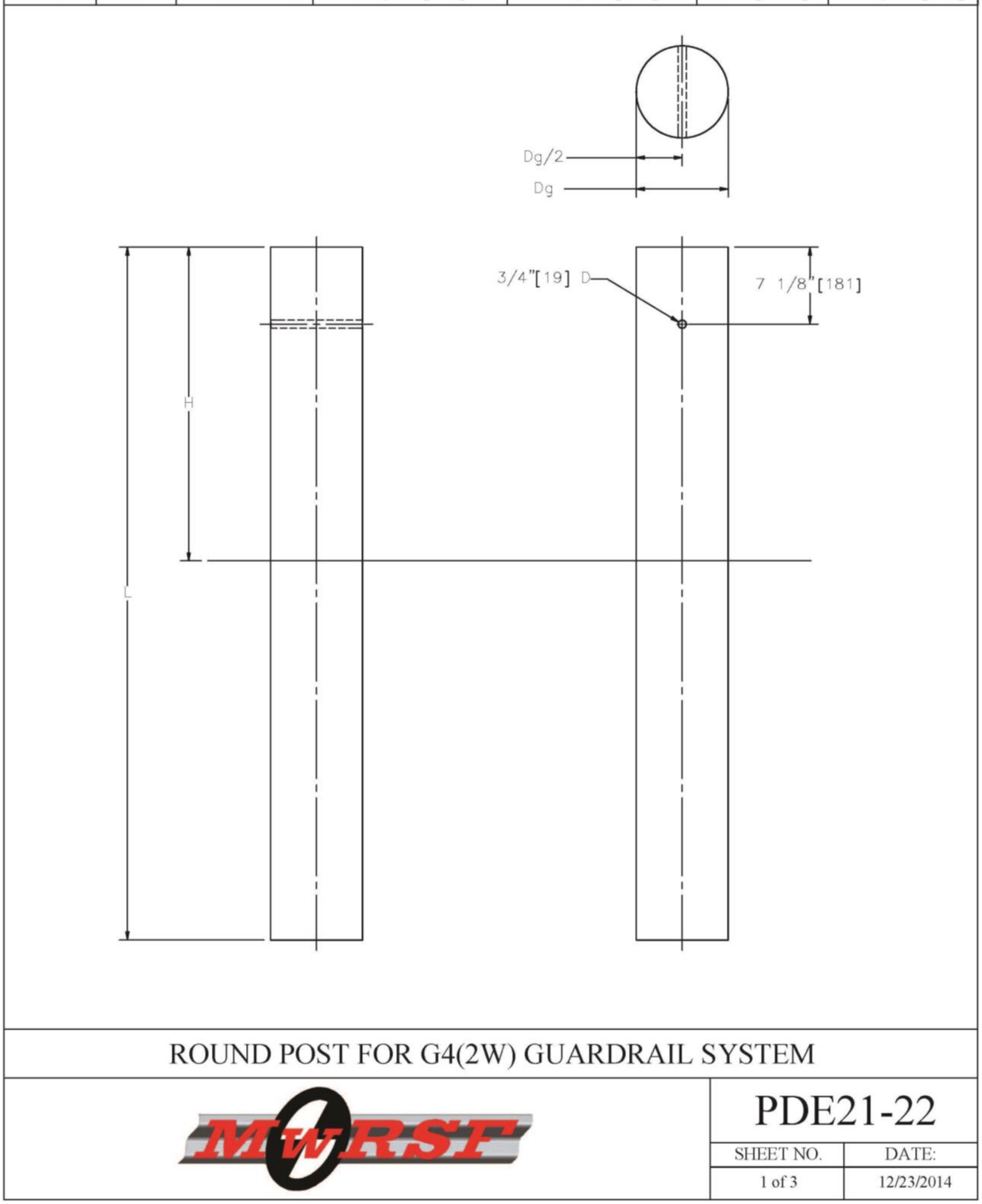

Figure C-5. Round Post for G4(2W) Guardrail System, Sheet 1

SPECIFICATIONS

The Ponderosa Pine (PP) round post 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 use of peeler cores is prohibited. See the table on Sheet 1 for diameters and lengths.

Groundline:
The groundline, for the purpose of applying these restrictions of ANSI 05.1 that reference the groundline, shall be defined as being located 35" [889] and 36" [914] from the butt end of each post for PDE21 and PDE22, respectively.

Size:
The size of the posts shall be classified based on their diameter at the groundline and their length. The groundline diameter shall be specified by diameter in 1/8" [3] breaks. The length shall be specified in 1" [25] 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" [76] longer. See the table on Sheet 1 for minimum and maximum diameters.

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 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 1 1/4" [32] at any point. Posts shall be free from reverse bends.

Splits, Checks, and Shakes:
Splits or ring shakes are not permitted in the top two thirds of the post. Checks are not permitted in the top two thirds of the post if wider than one third of the diameter if dry and wider than three eighths of the diameter if not dry. Splits exceeding the diameter in length are not permitted in the bottom one third of the post. A shake or check is permitted in the bottom one third of the post as long as it is not wider than one half of the butt diameter. (Note - check size is determined as the average measured penetration over its length.)

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3 1/2" [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 3/4" [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" [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] distance.

ROUND POST FOR G4(2W) GUARDRAIL SYSTEM

MwRSF	PDE21-22	
	SHEET NO.	DATE:
	2 of 3	12/23/2014

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

The posts shall have cross sectional properties as shown below:

Component	Post Material	Groundline 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]
PDE21	Ponderosa Pine	8 $^1/_2$ [216]	56.7 [36.6]	256.2 [106.7]	256.2 [106.7]	60.3 [988]	60.3 [988]
PDE22	Ponderosa Pine	8 $^5/_8$ [219]	58.4 [37.7]	271.6 [113.1]	271.6 [113.1]	63.0 [1032]	63.0 [1032]

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 (SGR04d or SGR04e). The PDE21 round post is used with the PDB23 timber block. The PDE22 round post is used with the PDB24 timber block. The round post (PDE21 and PDE22) and the timber block (PDB23 and PDB24) are attached to the RMW02a guardrail using a FBB04 guardrail bolt and nut with a FWC16a washer under the nut.

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ROUND POST FOR G4(2W) GUARDRAIL SYSTEM

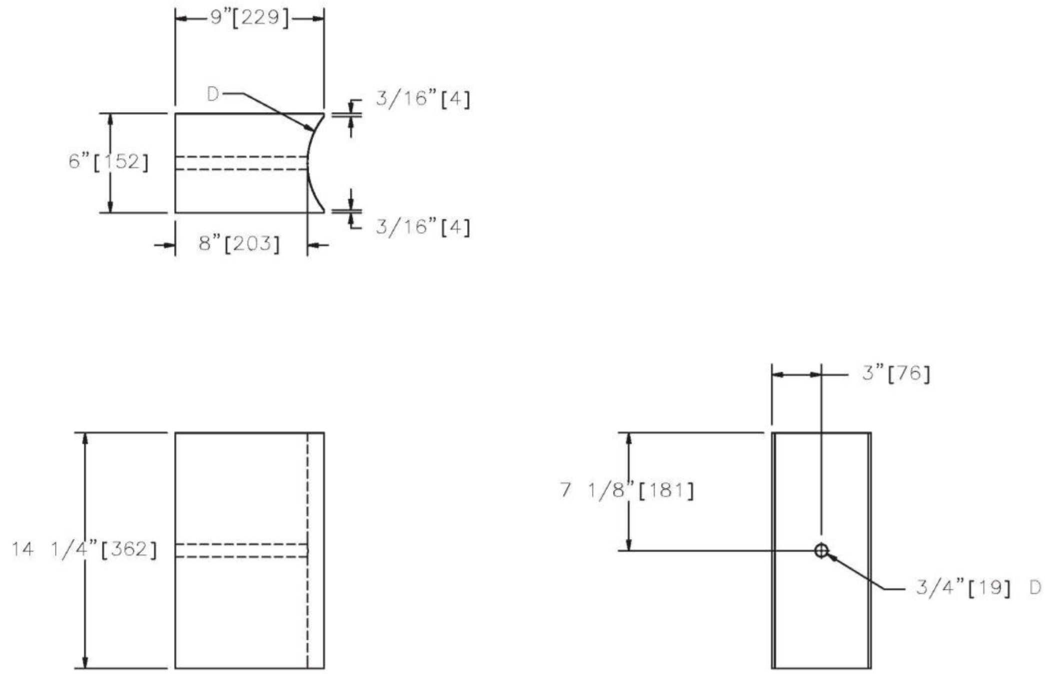
MwRSF

PDE21-22

SHEET NO.	DATE:
3 of 3	12/23/2014

Figure C-7. Round Post for G4(2W) Guardrail System, Sheet 3

Designator	System	Route Diameter, D	Wood Blockout Type
PDB23	SGR04e	9" [229]	Ponderosa Pine
PDB24	SGR04d	9 1/8" [232]	Ponderosa Pine



BLOCKOUTS FOR G4(2W) ROUND POST APPLICATIONS

PDB23-24	
SHEET NO.	DATE:
1 of 2	12/23/2014

Figure C-8. 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
PDB23	Ponderosa Pine	14¼" [362]	9" [229]	6" [152]	9" [229]
PDB24	Ponderosa Pine	14¼" [362]	9" [229]	6" [152]	9 1/8" [232]

INTENTED USE

This blockout is used with round wood post (PDE21 and PDE22) in G4(2W) guardrail systems along with Round Post variations (SGR04e and SGR04d), respectively.

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BLOCKOUTS FOR G4(2W) ROUND POST APPLICATIONS

MwRSF

PDB23-24	
SHEET NO.	DATE:
2 of 2	12/23/2014

Figure C-9. Blockouts for G4(2W) Round Post Applications, Sheet 2

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