Ponderosa Pine Round Posts as Alternative to Rectangular SYP Posts in Retrofit G4(2W) Guardrail Systems

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Over the last several decades, the southwestern United States experienced numerous forest fires, prompting a need for more preventive techniques. In the 1960s, the U.S. Department of Agriculture - Forest Service began managing fuels by using controlled-burn techniques. 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. With such vast quantities of timber thinnings, local producers within the timber industry deemed it necessary to further explore the use of undamaged Ponderosa Pine (PP) material as posts in guardrail systems. Two W-beam guardrail systems were identified that may be compatible with PP posts: the U.S. standard G4(2W) guardrail system and the Arizona DOT (AzDOT) G4(2W) guardrail system. Therefore, research was undertaken to determine the appropriate dimensions (diameter and length) and embedment depth of round PP posts for use within these two strong-post, W-beam guardrail systems.

Dynamic component tests on rectangular SYP posts and round PP posts with diameters between 8⅜ in. and 8¾ in. were performed to determine the appropriate diameter, length, and embedment depth for PP posts to be used as a surrogate for 6-in. x 8-in. rectangular Southern Yellow Pine (SYP) posts found in existing, strong-post, G4(2W) W-beam guardrail systems. In addition, one full-scale demonstration crash test was successfully performed according the Test Level 3 (TL-3) impact safety standards published in the National Cooperative Highway Research Program (NCHRP) Report No. 350 on a 175-ft long, G4(2W) guardrail system supported by 8½-in. diameter (ground line) by 64-in. long PP posts with a 35-in. embedment depth. A ¾-ton Chevrolet pickup truck impacted at a speed of 60.7 mph and an angle of 24.8 degrees. The G4(2W) guardrail system with PP posts adequately contained and redirected the pickup truck and met the NCHRP 350 TL-3 safety performance criteria.

Based on dynamic component testing, a PP post with an 8½-in. diameter, a 35-in. embedment depth, and a 64-in. length was approved for use as a surrogate in existing Arizona G4(2W) guardrail systems. Similarly based on the dynamic component testing, a PP post with an 8⅝-in. diameter, a 36-in. embedment depth, and a 65-in. length was also approved for use as a surrogate in existing U.S. standard G4(2W) guardrail systems. The demonstration test offered confidence to State Departments of Transportations interested in using round PP posts to repair damaged strong-post, W-beam guardrail systems configured with 6-in. x 8-in. rectangular SYP posts.

INTRODUCTION

Over the last several decades, the southwestern United States (U.S.) experienced numerous forest fires, prompting a need for more preventive techniques. In 2000, President Bill Clinton initiated the creation of the National Fire Plan, which 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 were recommended for development 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 Forest Service - USDA, (FS-USDA) developed an adaptation of the Midwest Guardrail System (MGS) that utilized SDT materials as timber posts (*5*, *6*). 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 quantities of timber thinnings, local producers within the timber industry deemed it necessary to further explore the use of undamaged 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 G4(2W) guardrail system. Although these W-beam 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 different post performance requirements for each system. Therefore, further research was undertaken with a collaborative effort between the Arizona Timber Industry, MwRSF, and FPL-FS-USDA, to determine the appropriate dimensions (diameter and length) and embedment depth of round PP posts for use within these two strong-post, W-beam guardrail systems.

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

TABLE 1 Wood Post Options for W-beam Guardrail Systems

Guardrail 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 G4(2W)	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)	8⅝ (219)	65 (1,651)	36 (914)

— Determined from Phase I project (7).
— Determined from Phase II project (8).

sufficient structural capacity, provide adequate lateral resistance, and exhibit reasonable energy dissipation characteristics during rotation in soil.

RESEARCH OBJECTIVE

The primary research objectives for the three-phase project was to determine the appropriate size and embedment depth for round PP posts in order to serve as a surrogate for standard 6-in. x 8-in. (152-mm x 203-mm) SYP posts used in both Arizona and U.S. crashworthy W-beam guardrail systems. The dynamic 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 (9). In addition, the study would examine the post-soil behavior for PP round posts and SYP rectangular posts subjected to impact loading. Following a successful dynamic component testing program, MwRSF researchers would request eligibility from Federal Highway Administration (FHWA) regarding the surrogate use of PP post sizes within existing Arizona and U.S. standard G4(2W) W-beam guardrail systems based on dynamic bogie testing results. In addition, a demonstration crash test according to the Test Level 3 (TL-3) safety performance criteria set forth in the NCHRP Report No. 350 would be conducted on the retrofit G4(2W) W-beam guardrail system to further confirm the crashworthiness of the system. This study was performed by MwRSF in cooperation with the FPL-FS-USDA, the Arizona Log & Timberworks, and the Arizona State Forestry Division.

DYNAMIC COMPONENT TESTING

Phase I of the PP equivalency study incorporated 17 dynamic component tests on various wood posts - six were conducted on rectangular SYP posts and 11 tests were 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) (*7*). Subsequently, this equivalent round PP post was recommended as a surrogate post for use in the Arizona G4(2W) W-beam guardrail system, as noted within Table 1.

Phase II of the PP equivalency study incorporated nine dynamic component tests on various wood posts – four were conducted on rectangular SYP posts and five tests were on round PP posts with diameters approximately between 8½ in. and 8-11/16 in. (216 mm and 221 mm). Based on the results of these component tests, an 8⅝-in. (219-mm) diameter PP post with a 36-in. (914-mm) embedment depth was found to provide strength and soil rotation resistance equivalent to the rectangular SYP post embedded 43¼ in. (1,099 mm) (*8*). Subsequently, this equivalent round PP post was recommended for use as a surrogate post for use in the U.S. standard G4(2W) W-beam guardrail system, as noted within Table 1. Within the Phase II study, enhanced grading criteria and materials specifications were compiled for the PP posts recommended for use in both Arizona and U.S. standard G4(2W) W-beam guardrail systems and are shown in Figure 1.

TEST REQUIREMENTS AND EVALUATION CRITERIA

Longitudinal barriers, such as W-beam guardrail systems, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on National Highway System (NHS). For retrofits of existing systems, these safety standards may consist of the guidelines and procedures published in NCHRP Report No. 350. According to TL-3 of NCHRP Report No. 350, longitudinal barrier systems must be subjected to two full- scale vehicle crash tests: (1) an 1,808-lb (820-kg) passenger car impacting at a speed of 62.1 mph (100.0 km/h) and at an angle of 25 degrees and (2) a 4,409-lb (2,000-kg) pickup truck impacting at a speed of 62.1 mph (100.0 km/h) and at an angle of 25 degrees. However, based on the success of prior small car testing on strong-post, W-beam guardrail systems, the 1,808-lb (820-kg) small car crash test was deemed unnecessary for this project (10-18). Details pertaining to the successful small car tests into strong-post guardrail systems can be found in the reference report (19)

The evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the guardrail to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These three evaluation criteria are described in greater detail in NCHRP Report No. 350. Finally, the full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

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 1 Grading criteria for round PP posts.

ARIZONA G4(2W) W-BEAM GUARDRAIL WITH ROUND PP POSTS

System Details

Design details for the retrofit G4(2W) guardrail system with PP posts are shown in Figure 2 The installation for the guardrail system consisted of 175 ft (53.3 m) of standard 12-gauge (2.66-mm) W-beam supported by round PP wood posts. Photographs of the test installation are shown in Figure 3.

The barrier utilized standard 12-ft 6-in. (3.81-m) long 12-gauge (2.66-mm) W-beam rails. The W-beam guardrail was mounted with a top-rail height of 28 in. (711 mm) throughout the entire system. The rail splices were located at post locations. All lap-splice connections between the rail sections were configured with the upstream segment in front of the downstream segment to minimize the potential for vehicle snag at the splice during the crash test.

The rail was supported by twenty-nine guardrail posts spaced at 75 in. (1,905 mm) on center. All twenty-five PP posts were placed in a compacted coarse, crushed limestone material that met Grading B of AASHTO M147-65, as found in NCHRP Report No. 350. The posts were installed using MwRSF's installation procedures which comply with the 2009 *Manual for Assessing Safety Hardware* (MASH) specifications (20). Post nos. 3 through 27 consisted of a nominal 8½ in. (216 mm) diameter at groundline, a 64-in. (1,626-mm) length, and used a soil embedment depth of 35 in. (889 mm). A 6-in. wide x 8-in. deep x 14¼-in. long (152-mm x 203-mm x 362-mm) routed PP wood spacer blockout was used to block the rail away from the front face of each PP post.

The upstream and downstream ends of the guardrail installation were configured with a trailing-end anchorage system. This guardrail anchorage system was utilized to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system and now part of a crashworthy, downstream trailing end terminal (21-24). Post nos. 1, 2, 28, and 29 were breakaway cable terminal (BCT) timber posts that were inserted into 6-ft (1.8-m) long, steel foundation tubes.

Phase III Full-Scale Crash Testing – Test No. AZRP-1

For demonstration test no. AZRP-1, a 4,412-lb (2,001-kg) pickup truck impacted the modified Arizona G4(2W) W-beam guardrail system that was supported by 8½-in. (216-mm) nominal diameter PP posts at a speed of 60.7 mph (97.7 km/h) and an angle of 24.8 degrees. A summary of the test results and time-sequential photographs are shown in Figure 4. The critical impact point was determined to be 185 in. (4.699 mm) upstream from the centerline of post no. 15 which was selected using the CIP plots found in Section 3.4 of NCHRP Report No. 350 to maximize pocketing and the probability of wheel snag. The actual point of impact was 182¼ in. (4,629 mm) upstream from the centerline of post no. 15. At 0.342 sec after impact, the vehicle became parallel to the guardrail system with a speed of 33.3 mph (53.6 km/h). At 0.718 sec, the vehicle exited the guardrail at an angle of 21.3 degrees and at a speed of 25.5 mph (41.1 km/h). The vehicle was smoothly redirected. The exterior vehicle damage was moderate, as shown in Figure 5, and the interior occupant compartment deformations were below the previously-recognized NCHRP Report No. 350, with a maximum of 5½ in. (140 mm) in the wheel well and toe pan area. As shown in Figure 5, damage to the barrier was moderate, consisting mostly of

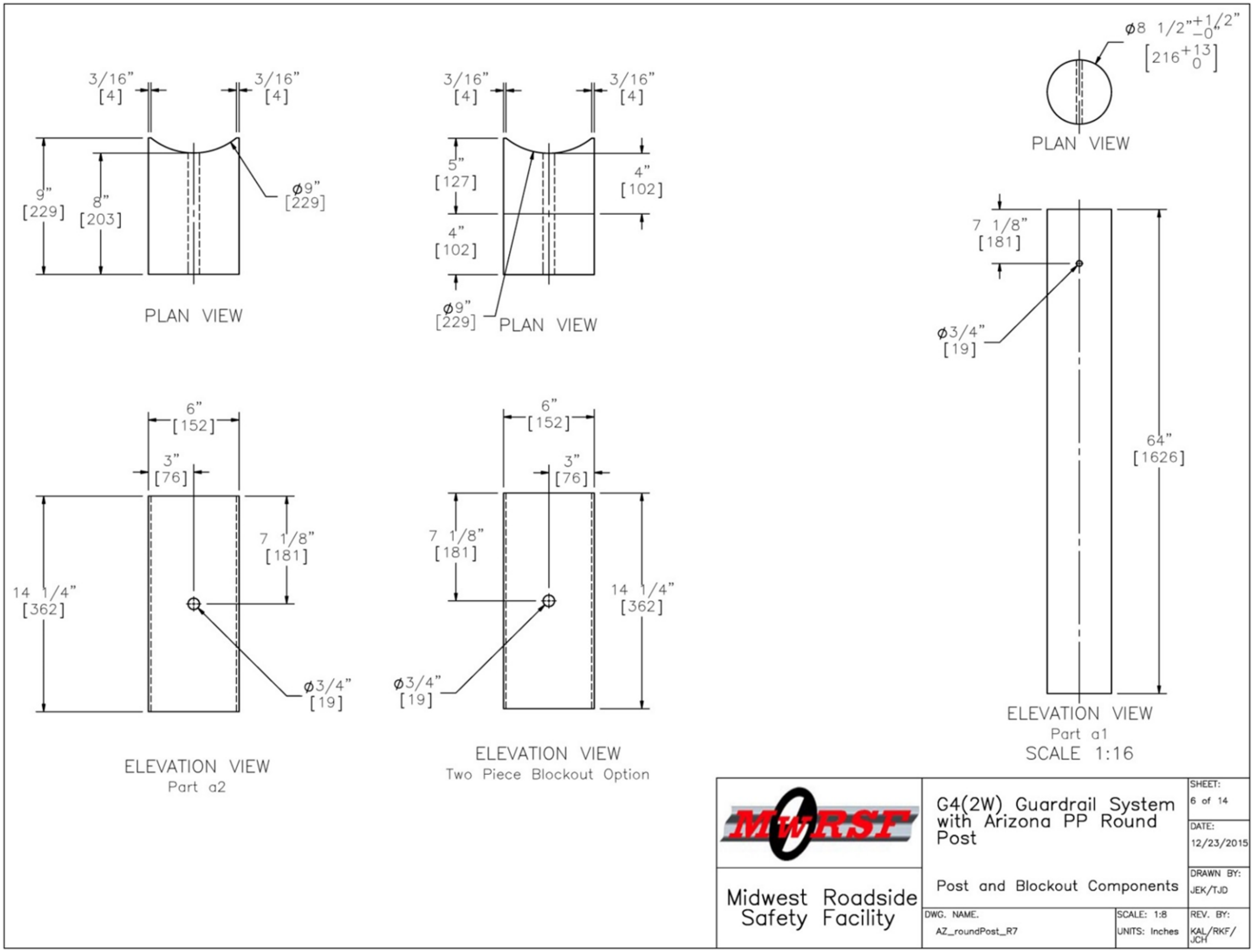
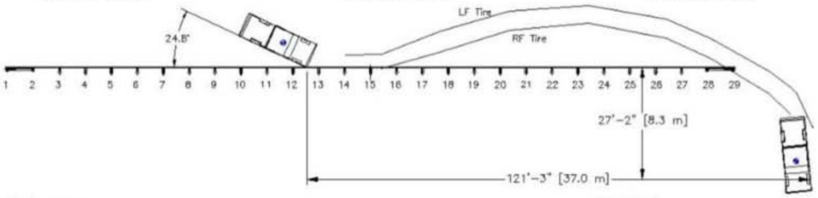
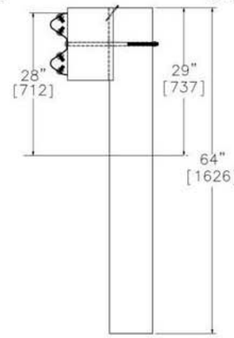


FIGURE 2 Round PP post details for Arizona G4(2W) guardrail system.

FIGURE 3 Arizona G4(2W) guardrail system with round PP posts.

0.000 sec 0.116 sec 0.266 sec 0.364 sec 0.718 sec





- Test Agency ....MwRSF
- Test Number....................AZRP-1
- Date 12/8/2015
- NCHRP Report No. 350 Test Designation No. 3-11
- Test Article.................... Arizona G4(2W) supported by 8½-in. (216-mm) PP posts
- Total Length .... 175 ft (53.3 m)
- Key Component – Steel W-Beam Rail
  - Thickness.................... 12-gauge (2.66 mm)
  - Top Mounting Height.................... 28 in. (711 mm)
- Key Component – Wood Post
  - Shape .... 8½ in. (216-mm) nominal diameter
  - Length.................... 64 in. (1,626 mm)
  - Spacing .... 75 in. (1,905 mm)
  - Embedment Depth.................... 35 in. (889 mm)
  - Material ....Graded Ponderosa Pine
- Key Component – Routed Wood Blockout
  - Size....................6 x 9¼ x 14¼ in. (152 x 235 x 362 mm)
  - Material .... Ponderosa Pine
- Soil Type ....AASHTO M147-65(1990) Grade B Coarse Crushed Limestone
  - Compaction Method....................MwRSF Compaction Methods per MASH
- Vehicle Make /Model ....1993 Chevrolet C2500 Pickup Truck
  - Curb.................... 4,629 lb (2,100 kg)
  - Test Inertial .... 4,412 lb (2,001 kg)
  - Gross Static .... 4,412 lb (2,001 kg)
- Impact Conditions
  - Speed.................... 60.7 mph (97.7 km/h)
  - Angle....................24.8 deg
  - Impact Location .... 182¼ in. (4,629 mm) upstream of post no. 15
- Impact Severity (IS)....................95.4 kip-ft (129.3 kJ)
- Exit Conditions
  - Speed.................... 25.5 mph (41.1 km/h)
  - Angle ....21.3 deg
- Vehicle Stability....................Satisfactory
- Vehicle Stopping Distance .... 121 ft – 3 in. (37.0 m) downstream
  - ....27 ft – 2 in. (8.3 m) laterally behind
- Vehicle Damage ....Moderate
  - VDS.................... 1-RFQ-5
  - CDC 1-RYEW4
  - OCDI....................RF010100000
  - Maximum Interior Deformation .... 5½ in. (140 mm)
- Test Article Damage....................Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 18 in. (457 mm)
  - Dynamic.................... 28.8 in. (732 mm)
  - Working Width .... 41.1 in. (1,044 mm)
- Transducer Data

Evaluation Criteria		Transducer			NCHRP 350 Limit
		SLICE-1	SLICE-2 (Primary)	Video Analysis	
OIV ft/s (m/s)	Longitudinal	-19.89 (-6.06)	-20.51 (-6.25)	-20.01 (-6.10)	≤ 39.4 (12)
	Lateral	-18.58 (-5.66)	-18.35 (-5.59)	-19.03 (-5.80)	not required
ORA g's	Longitudinal	NA	NA	-7.01	≤ 20
	Lateral	NA	NA	-10.47	not required
MAX ANGULAR DISP. deg.	Roll	NA	NA	5.37	not required
	Pitch	NA	NA	Not available	not required
	Yaw	NA	NA	-45.42	not required

FIGURE 4 Summary of test results and sequential photographs, Test AZRP-1.

FIGURE 5 Vehicle damage and barrier damage, Test AZRP-1.

Deformed w-beam rail, disengaged w-beam rail from the posts, fractured wood posts, split wood blockouts displaced posts in the soil, and contact marks on a section of guardrail. The maximum lateral dynamic rail and post deflections were 28.8 in. (732 mm) at the rail between the midspan between post nos. 14 and 15 and 21.3 in. (541 mm) at post no. 14, respectively, as determined from high-speed digital video analysis. The working width of the system was 41.1 in. (1,044 mm), also determined from high-speed digital video analysis. The longitudinal occupant risk measures were below the required values, and the test vehicle showed no tendency to roll over. Therefore, test no. Azrp-1 was determined to be acceptable according to the tl-3 safety performance criteria found in nchrp report no. 350.

SUMMARY AND CONCLUSIONS

Round PP post alternatives for use as replacement posts in existing Arizona and U.S. standard G4(2W) W-beam guardrail systems were developed. An 8½-in. (216-mm) nominal diameter PP post with a 35-in. (889-mm) embedment depth and a 64-in. (1,626-mm) length was confirmed as a surrogate for use in existing Arizona G4(2W) guardrail systems based on dynamic component testing. Similarly, based on dynamic component testing, an 8⅝-in. (219-mm) nominal diameter PP post with a 36-in. (914-mm) embedment depth and a 65-in. (1,651-mm) length was found to be a surrogate in existing U.S. standard G4(2W) W-beam guardrail systems. The modified Arizona and modified U.S. standard G4(2W) guardrail systems with the specified PP posts are eligible for Federal reimbursement and are suitable for use on Federal-aid highways (25). The specific guardrail systems are those that have either met or been grandfathered under the impact safety standards published in the NCHRP Report No. 350.

A full-scale crash test was performed to further demonstrate the crashworthiness of the 28 in. (711 mm) tall Arizona G4(2W) W-beam guardrail system when supported by 8½-in. (216-mm) nominal diameter PP post with a 35-in. (889-mm) embedment depth and a 64-in. (1,626-mm) length. The demonstration test was conducted according to the TL-3 safety performance criteria published in NCHRP Report No. 350 and confirmed that the specified PP post as a suitable surrogate for use in existing Arizona G4(2W) W-beam guardrail systems.

Special attention should be directed toward the proper inspection of timber materials and emphasis for timber suppliers to follow the published PP round-post dimensions and grading criteria as shown in Figure 1. These measures should ensure that the PP posts are fabricated from suitable wood, have adequate strength, provide similar post-soil behavior to the rectangular SYP posts studied (7-8), and allow for G4(2W) guardrail systems to perform in an acceptable manner when using either round PP posts or rectangular SYP posts.

Federal, State, and local highway agencies could benefit from the use of surrogate, round PP posts to retrofit existing G4(2W) guardrail systems. Installation of the modified G4(2W) guardrail systems using round timber posts could: (1) continue to provide motorist safety along our nation's highways and roadways; (2) increase markets for wood products across the U.S. as well as in the State of Arizona; and (3) help to reduce the risk of devastating forest fires across the country.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Forest Products Laboratory of the USDA - Forest Service, the Arizona Log & Timberworks, and the Arizona State Forestry Division. This report does not constitute a standard, specification, or regulation.

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