ABSTRACT: Round guardrail posts may provide an important value-added option for small-diameter thinnings (SDTs). Such posts require minimum processing and are believed to have higher strength for the equivalent rectangular volume. A modified version of the Midwest Guardrail System (MGS) was developed, tested, and evaluated utilizing small-diameter, round wood posts in lieu of steel wide-flange posts. This system has been accepted for use on the national highway system by the United States Department of Transportation, Federal Highway Administration. The barrier system was modified using three different timber species - Douglas Fir, Ponderosa Pine, and Southern Yellow Pine. Barrier VII computer simulation, combined with cantilever post testing conducted both in a rigid sleeve and in soil, were used to determine the required post diameter for each species. The final recommended nominal sizes were determined. A grading criteria limiting knot size and ring density was established for each species. The minimum ring density for each post species was to equal or exceed 6 rings-per-inch (rpi) for Douglas Fir, 6 rpi for Ponderosa Pine, and 4 rpi for Southern Yellow Pine. Two of the guardrail systems, one using Douglas Fir posts and another using Ponderosa Pine posts, were full-scale vehicle crash tested and reported in accordance to the Test Level 3 (TL-3) requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 350. Crash testing of the third system, using Southern Pine posts, was not conducted based on the prior successful testing of a standard W-beam guardrail with 184-mm (7.25-in.) diameter, Southern Yellow Pine posts as well as comparable post design strength to that of the other two species. The two full-scale crash tests showed that the modified MGS functioned adequately for both wood species. Three round wood post alternatives are recommended as an acceptable substitute to the standard W152x13.4 (W6x9) steel post utilized in the MGS.


1 INTRODUCTION

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

One of the most commonly used fire prevention techniques is fuel management, an idea that has been around for many years. In the 1960’s, the U.S. Department of Agriculture (USDA) - Forest Service began managing fuels by using controlled burn techniques [2] where fires are initiated in areas where they can be contained in order to consume the small-diameter forest thinnings (SDTs) that might serve as fuel for future fires. Although this controlled burn technique has generally been effective, it has been stated to offer no economic benefits while carrying many risks.
Today, there are many uses for the small diameter trees that make up the majority of the forest thinnings. Uses for these thinnings include lumber, structural roundwood, wood composites, wood fiber products, compost, mulch, energy, and fuels [3]. Guardrail post production is one possible application for using SDTs. SDT’s used within guardrail systems provide a new application for thinnings while also reducing the cost of the barrier system. This poster summarized research that was conducted to better determine and evaluate the structural properties of SDT material in order to expand the use of round wood in this new value-added market (Figure 1).

2 BACKGROUND LONGITUDINAL BARRIER SYSTEMS

For more than 50 years, longitudinal barrier systems have been constructed along U.S. highways and roadways to prevent errant motorists from impacting dangerous fixed objects or traversing hazardous roadside geometries found beyond the edge of the traveled way. Although several different longitudinal barrier systems can be found throughout the U.S., strong-post W-beam guardrail systems have historically been the most common. Typical design details for these common barrier systems can be found in the American Association of State Highway and Transportation Officials’ (AASHTO’s) Roadside Design Guide [4] as well as in AASHTO’s Task Force 13 Report, A Guide to Standardized Highway Barrier Hardware [5].

Longitudinal, W-beam barrier systems generally consist of a W-beam guardrail element, evenly spaced support posts, and rigid guardrail blockouts or post spacers. The W-beam rail is available in two thicknesses, 2.66 mm (12 gauge) or 3.42 mm (10 gauge), although most installations have used 2.66-mm (12-gauge) rail sections. Three post types have been commonly used in strong-post, W-beam guardrail systems – W152-mm x 13.4 (W6x9) steel posts, 152-mm x 203-mm (6-in. x 8-in.) rectangular wood posts, and 184-mm (7.25-in.) diameter round wood posts. From these post options, round timber posts have traditionally been the least costly. Although round SYP posts have been the most economical, large-scale implementation of round-post, W-beam barrier systems has been mostly limited to the State of Texas, with most of the research and development of these barrier systems performed at the Texas Transportation Institute [6-9]. As such, there exists significant opportunities for the increased use of round posts of multiple timber species into crashworthy, strong-post, W-beam guardrail systems.

In 2000, the Midwest Roadside Safety Facility (MwRSP), in cooperation with the Midwest States’ Regional Pooled Fund Program, developed a new guardrail system that would improve barrier performance for higher center-of-mass vehicles, provide reasonable barrier height tolerances, and reduce the potential for W-beam rupture [10-13]. This new W-beam guardrail system later became known as the “Midwest Guardrail System” or MGS. Design changes incorporated into the W-beam barrier system included: a nominal W-beam rail top mounting height of 787 mm (31 in.), a guardrail post embedment depth of 1,016 mm (40 in.), an increased blockout depth from 203 to 305 mm (8 to 12 in.), and a repositioning of the guardrail splice from a post to a mid-span location. Prior crash testing has demonstrated that the MGS was capable of containing and redirecting both ¾-ton pickup trucks and small cars according to current impact safety standards. Based on these successes, the researchers determined that the MGS would be a beneficial system for use with SDT round posts.

3 METHODS

Three objectives were identified for this research project. The first objective was to determine the structural properties of round wood posts manufactured from Douglas Fir (DF), Ponderosa Pine (PP), and Southern Yellow Pine (SYP) when subjected to impact loading conditions. A second objective was to determine an acceptable diameter and grading specification for each wood species as well as the post embedment depths in order to allow their use as a substitute for the rectangular Southern Yellow Pine and wide-flange steel posts currently used in guardrail applications, more specifically the Midwest Guardrail System. Non-linear, dynamic vehicle-to-barrier impact analysis was also utilized to establish failure criteria for the MGS as well as to evaluate barrier performance. The final research objective was to conduct a safety performance evaluation of the MGS with round wood posts according to the guidelines found in the National Cooperative Highway Research Program (NCHRP) Report No. 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features [14]. At the completion of the project, an installation manual and standard CAD plans were prepared for the round-post, highway guardrail systems using Ponderosa Pine, Douglas Fir, and Southern Yellow Pine.

3.1 SAMPLE PREPARATION

Douglas Fir (DF) and Ponderosa Pine (PP) round post were investigate as alternate species to Southern Pine. DF and PP posts were sized to carry a bending moment equivalent to that of the Southern Pine posts. Since woods strength can drastically change with variation in species, ring density, knot size and density, moisture content, and even region of origin, three categories of posts were defined in order to investigate the effects of the two most influential variables, knots and ring density. The selected categories were low ring density without knots or small knots (LRD-SKN), low ring density with big knots (LRD-BKN), and high ring density without knots or small knots (HRD-SKN). Posts were categorized based on ring density, knot frequency, and knots. Posts with 4 or fewer rings-per-inch were defined as low ring density (LRD) and 6 or more rings-per-inch were defined as high ring density (HRD). Posts with any knots larger than 64 mm (2.5 in.) in diameter were classified in big knot category (BKN), while posts with knots that were less than 38 mm (1.5 in.) in
diameter were classified in the small knot category (SKN) and considered to be without knots. A portion of the testing was intended to isolate the properties of posts in these three categories, and a portion was intended to determine the properties of the random population. Additional details regarding the post population, sampling methodology, and preservative treatments have been previously reported [16-19].

3.2 COMPONENT TESTING

The component testing program consisted of two distinct phases. Phase I testing included the static and dynamic evaluation of the structural properties for the three wood species when subjected to cantilevered loading. The static tests for Phase I were conducted using a million pound test frame at the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory (FPL), using a loading rate of 0.008 m/min (0.3 in./min). Loads were recorded on a 222.4-kN (50,000-lb) load cell in Round 1 and a 133.4-kN (30,000-lb) load cell in Round 2. Deflections were recorded using linear variable differential transducers (LVDTs). The Phase I dynamic tests were conducted at the MwRSF using a 728-kg (1605-lb) rigid-frame bogie vehicle, as shown in Figure 2. The bogie vehicle traveled at approximately 32 km/h (20 mph) in Round 1 and 21.7 km/h (13.5 mph) in Round 2. All dynamic tests recorded the force versus time profiles using onboard accelerometer data. For Phase I, two rounds of testing were conducted in order to determine the optimum size of the round posts. During Phase II, dynamic testing of posts embedded in soil was performed on each wood species using a cantilevered loading while varying the soil embedment depths (Figure 3).

3.3 COMPUTER SIMULATIONS

Barrier VII [20] simulations were completed for a baseline model as well as using models with 1, 2, 3, and 4 consecutive weak posts. The results did not show a distinct point at which one additional failed post would cause the system to drastically fail. However, a four consecutive post failure matched a previous limit where it was believed that a maximum deflection of 1,321 mm (52 in.) was too large based on reasonable engineering judgment. Therefore, the definition of system failure was maintained as the fracture of four consecutive weak posts but subject to change based on subsequent testing. A detailed discussion and tabulation of the Barrier VII results can be found in references [15,17], including the determination of the critical impact point (CIP) for use in the crash testing program.

3.4 CRASH TESTS

Two, full-size barrier installations were constructed for testing and evaluation using the Midwest Guardrail System – one using round Douglas Fir posts and the second using round Ponderosa Pine posts. Each test installation consisted of 55.25 m (181 ft - 3 in.) of standard 2.66-mm (12- gauge) thick, W-beam guardrail supported by wood posts, as shown in a photograph of the test installation (Figure 1). Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. The Crash tests were conducted according to NCHRP Report No. 350 Test Designation 3-11. The 2,018-kg (4,450-lb) pickup truck impacted the test article at a speed of 100.0 km/h (62.14 mph) and an angle of 25.5 degrees. The target critical impact point (CIP) was 953 mm (37 ½ in.) downstream of the centerline of post no. 12. Figure 4 shows the time-lapse photography for the Douglas Fir Crash test. Figure 5 shows the downstream view of this test. The photographs of the PP tests were similar.
RESULTS

The analysis of the test results for both the DF and PP MGS utilizing round posts (Figure 6) adequately contained and redirected the test vehicle with controlled lateral displacement of the guardrail system. The post criteria developed for DF PP and SP MGS are provided in Table 1. The size and grading criteria were developed after reviewing the static and dynamic test results, the population distribution of knots and ring density, and the computer simulation results and the dynamic test results. The criteria were chosen to be tight enough to reduce the diameter of posts as much as possible, but relaxed enough to allow a high percentage of the posts to qualify.

<table>
<thead>
<tr>
<th>Species</th>
<th>Diameter at Ground-line</th>
<th>Knot Size</th>
<th>Ring Density Rings per inch (rpi)</th>
<th>Slope of Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir</td>
<td>184 mm 7 ¼ in.</td>
<td>≤38 mm 1 ½ in.</td>
<td>≥6</td>
<td>1:10 or better</td>
</tr>
<tr>
<td>Ponderosa Pine</td>
<td>203 mm 8 in.</td>
<td>≤89 mm 3 ½ in.</td>
<td>≥6</td>
<td>1:10 or better</td>
</tr>
<tr>
<td>Southern Pine</td>
<td>190 mm 7 ½ in.</td>
<td>≤64 mm 2 ½ in.</td>
<td>≥4</td>
<td>1:10 or better</td>
</tr>
</tbody>
</table>
5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Round, Douglas Fir, Ponderosa Pine, and Southern Yellow Pine timber posts were developed for use in the Midwest Guardrail System (MGS). The wood-post option for the MGS provides an additional market for small-diameter thinnings, helps to reduce the risk of devastating forest fires across the country, increases the U.S. and individual state timber industries, as well as reduces the cost of the MGS for the State Departments of Transportation, the National Parks, and other local and county governments. The modified MGS, using a 940-m (37-in.) post embedment depth, was successfully crash tested according to the TL-3 criteria found in NCHRP Report No. 350. Based on the research results summarized in this poster and described in more detail in [21], the round-post MGS designs have been accepted for use on the National Highway System (NHS) by the Federal Highway Administration (FHWA) [22].

Although the initial research and determination of post sizes were based on a barrier system that was predicted to fail with the fracture of four consecutive posts, full-scale crash testing demonstrated that the failure criteria exceeded this prediction. In the Douglas fir crash test, seven consecutive posts failed, yet the system effectively redirected the impacting vehicle. This result indicates that the round-post MGS has the capability to perform in an acceptable manner when more than four consecutive posts fracture.

These research results have demonstrated the capability for the MGS to be installed with alternative posts. At this time, only three timber alternatives have been investigated. However, the research team believes that other post alternatives would perform in an acceptable manner with the MGS, including posts with differences in size, shape, strength, or material. Of course, all of these alternatives would need to be tested and approved prior to installation.

Successful barrier performance was obtained using either Douglas Fir or Ponderosa Pine posts. System details were also developed for a round-post, Southern Yellow Pine barrier system, even though an additional crash test was not performed. For the Douglas Fir and Ponderosa Pine post systems, dynamic barrier deflections were found to be 1,529 mm (60.2 in.) and 956 mm (37.6 in.), respectively. In comparison, the steel-post MGS was evaluated in test no. NPG-4 under similar impact conditions and resulted in a dynamic deflection equal to 1,094 mm (43.1 in.) [11-12]. As such, it is apparent that the Ponderosa Pine post MGS has similar lateral barrier stiffness to that of the steel-post MGS. Therefore, the Ponderosa Pine post MGS should be capable of being attached to existing thrie beam approach guardrail transition designs in a similar manner to that already used for the steel-post MGS. However, the Douglas Fir post MGS resulted in a 435 mm (17.1 in.) increase in dynamic rail deflection to that observed for the steel-post MGS. Therefore, the Douglas Fir post MGS should not be directly attached to existing thrie beam approach guardrail transitions until additional research is completed. Further research is needed to develop an intermediate stiffened guardrail section used to connect the Douglas Fir post MGS to existing thrie beam approach guardrail transition systems. As an alternative, future research could be used to determine a slightly larger Douglas Fir post diameter that would provide similar MGS barrier deflections to those observed with both the Ponderosa Pine and steel post MGS.

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7 REFERENCES

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