

Nondestructive Evaluation of Timber Highway Guardrail Posts

James P. Wacker¹, Xiping Wang², David E. Kretschmann³, Douglas R. Rammer⁴

ABSTRACT: Timber post guardrail systems have been utilized in several regions of the U.S. due to their beneficial energy absorbing characteristics during vehicle impacts. These posts are not routinely inspected and replacement decisions are rather arbitrary. The Federal Highway Administration recently placed emphasis on new asset management strategies that actively assess condition of all highway structures. This paper describes a project aimed to develop inspection protocols for embedded timber guardrail post systems. Pulse-echo acoustic techniques were utilized to measure the soundness of the embedded portion of several timber guardrail posts. Field tests were conducted on both retired and new posts in-service. Laboratory tests for cantilevered post strength were also conducted on salvaged posts after removal from service. The preliminary results indicate that pulse-echo acoustic testing shows potential as an effective nondestructive method of inspecting guardrail post in-service.

KEYWORDS: guardrail, post, timber, pulse-echo, nondestructive, inspection, acoustic, red pine, white pine

1 INTRODUCTION

Treated timber guardrail posts are routinely used along USA highways to protect motorists from potential safety hazards within the right-of-way. Southern Pine has historically been the primary species used for this application. However, many alternative wood species, including red pine and white pine, are being utilized over the past several years. The primary advantage of using timber posts are their energy absorbing characteristics during vehicle impacts. The inherent flexibility of timber helps to reduce the severity of impact forces on the vehicle occupants.

Recently, the Federal Highway Administration (FHWA) has required states to shift towards more proactive management strategies with regard to their transportation infrastructures assets. As states begin to implement asset management strategies, they need to develop new techniques for measuring life-cycle cost for various material & design options. This will provide reliable data for estimating the service life of different

transportation structure systems. Longitudinal barriers, such as the flexible steel guardrail with treated timber post option, have traditionally been replaced after fifteen or twenty years of continuous service.

In order to develop new inspection protocols for their timber guardrail posts, the Wisconsin Department of Transportation (WI-DOT) entered into a cooperative research effort with the USDA Forest Products Laboratory (FPL). This paper will summarize the overall project and summarize preliminary findings.

2 RELATED LITERATURE

Unfortunately, the amount of deterioration in wood guardrail posts cannot easily be determined by visual field inspection, so many degraded posts go unnoticed by state maintenance personnel [1]. Much of the literature on highway guardrail posts focused on their dynamic performance under vehicle impact loadings. There is no known literature that applies various non-destructive techniques to timber guardrail posts.

However, several nondestructive techniques have been investigated for evaluating timber piles in-service. Chen and Kim [2] reported that dispersive wave propagation tests were found to be a promising means of evaluating the degree of hollowness in timber piles. They studied 7 installed timber piles in the field, and 2 salvaged timber piles, an acrylic cylinder and a timber post in the laboratory. The timber post measured 100mm by 100mm by 5.5m and included an array of drilled holes in order to simulate marine borer damage. The test instrumentation included two accelerometers attached to the side of the pile at exposed portion near its top. An

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impact hammer was used (side impact) for introducing dispersed sound waves and a digital oscilloscope for capturing the response data. Their data analysis was performed by two different methods: the Fourier transform method, and the short kernel method. The short kernel method was more effective at detecting the artificial damage in the laboratory timber post evaluations. A related nondestructive testing technique for evaluating the length of embedment of timber piles is reported by Holt et al [3]. It used a single accelerometer to measure the time between reflected wave signals and was shown to estimate the embedment length within ± 10 percent. The so-called *Pile Integrity Test* has recently been standardized in ASTM Standard D5882 [4] *Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations*. A thorough description of the various field techniques for evaluating embedded timber piles is provided by White et al [5]. Additional study is needed to determine if a modified nondestructive technique using the pulse-echo acoustic approach can be a reliable inspection tool for timber guardrail posts.

3 OBJECTIVE AND SCOPE

3.1 OBJECTIVE

Pulse-echo nondestructive testing techniques were investigated for measuring the in-situ internal integrity of treated timber guardrail posts. The primary objective was to develop an inspection protocol that could detect internal deterioration of in-service timber guardrail posts. A secondary objective was to develop techniques for measuring post embedment depth.

3.2 SCOPE

Field testing was conducted at two test locations in the state of Wisconsin. A total of forty old and forty new posts were evaluated while in-ground and out-of-ground. Cantilevered bending tests, along with additional NDE scanning were conducted on 40 old posts after they were removed from service.

4 EXPERIMENTAL TEST SETUP

4.1 NONDESTRUCTIVE PULSE-ECHO ACOUSTIC TESTING

The pulse-echo testing technique requires access to one end of timber guardrail post as shown in Figure 1. First, a uniaxial accelerometer is attached to the topside end grain with an adhesive or lag screw. Next a compression sound wave is created by impacting the end grain with small hammer. A digital oscilloscope records the reflecting waves as they propagate through timber post. Three replicate files, using two different sized hammers, were recorded for each test post. Pulse-echo testing of a weathered guardrail post at the Merrimac site is shown in Figure 2. Older posts represent a challenge in developing adequate adhesion of the accelerometer to the coarse end grain. In some cases, the end grain was flattened with a hammer prior to conducting pulse-echo testing. A typical wave signal response from an installed guardrail post is provided in Figure 3.

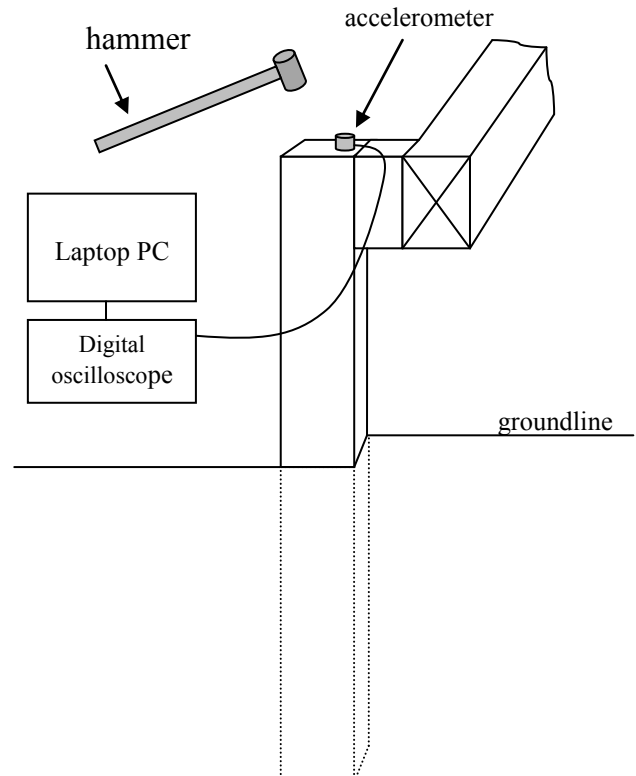


Figure 1: Typical test setup for pulse-echo tests on guardrail posts in-service.



Figure 2: Pulse-echo acoustic testing of an old guardrail post in the field

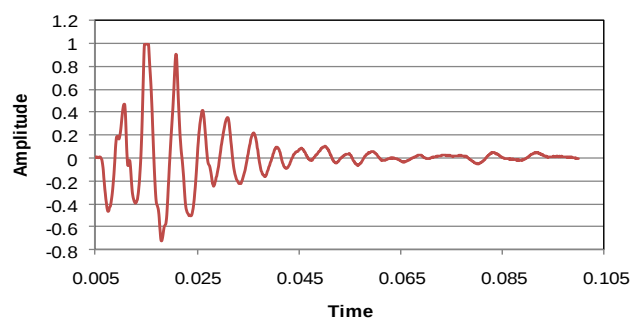


Figure 3: Typical wave signal response taken from a guardrail post recently installed in the field

The wave signal data files were analyzed with a Labview software program. Initially, the entire data file was converted from the time domain into the frequency domain using Fast Fourier Transformation (FFT) methods. By viewing the entire wave signal file in the frequency domain, all of the recorded frequencies were easily identified which assisted with further analyses. The dominant frequency present in the frequency spectrum was recorded from the full field FFT. Next, data interpretation was further refined by analysis of a truncated wave signal. Data time limits were selected based on the location of maximum and minimum values from the wave signal were selected with upper and lower time limits. This truncated wave signal data was also converted into the frequency domain using FFT methods. Figure 4 shows how the truncated wave signal was selected for more robust analysis of the wave signal. At the Royalton test site, operation of construction equipment during testing introduced additional frequencies in the old-post wave signals and presented additional analysis issues.

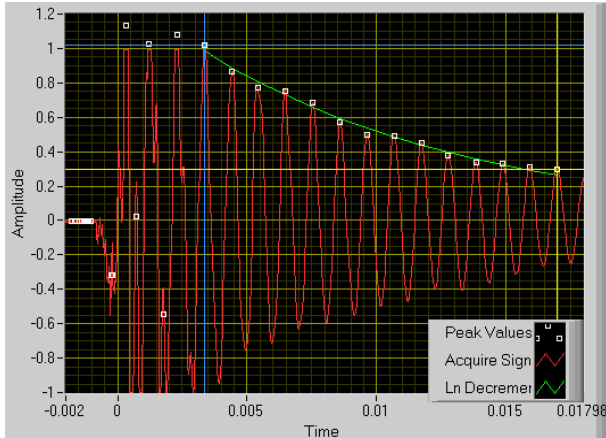


Figure 4: Analysis of reflected wave signal using a custom Labview® program.

4.2 NONDESTRUCTIVE PARALLEL-TO-GRAIN STRESS WAVE TESTING

Stress wave measurements were collected along the longitudinal axis of all new guardrail posts as shown in Figure 5. These tests were performed in order to determine the inherent sound velocity for each post. A stress wave timing device (Fakopp Enterprise, Hungary) was used to measure the time it takes for sound waves to travel through the 2m post length. In addition, similar stress wave measurements were collected along the exposed sides of the guardrail posts after installation.

For the installed posts, the stress wave times were recorded over a 0.61m gauge length at the post side. The unique velocity for each post was then derived by the equation (1) listed below:

$$V = \frac{l}{\Delta t} \quad (1)$$



Figure 5: Parallel-to-grain stress wave timing of new posts prior to installation at the Royalton test site

where $l = 0.61\text{m}$ gauge length, t = transit time, and V = velocity. With the velocity known for each post, and the wave signal period derived from signal analysis, the total length of the guardrail post can be calculated from equation (2) listed below:

$$L = V \times \frac{\Delta t}{2} \quad (2)$$

where L = overall post length, t = time of wave period, and V = velocity as determined by equation (1). To determine the embedment length, the above-ground length of the post must be subtracted from the overall post length in equation (2).

4.3 NONDESTRUCTIVE PERPENDICULAR-TO-GRAIN STRESS WAVE TESTING

All 40 old posts salvaged from both test sites were scanned with a stress wave timing device (Fakopp Enterprise, Hungary) to measure internal deterioration levels. Perpendicular-to-grain stress wave times were collected as described in Figure 6. The data point grid consisted of two reference lines with testing points spaced at 152mm intervals applied to the opposing wide faces of the guardrail posts, beginning at the exposed “above-ground” post end. Stress wave transit times were then normalized as transmission rates given as microseconds per meter.

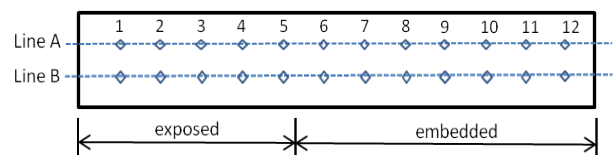


Figure 6: Testing grid for perpendicular-to-grain stress wave testing of salvaged guardrail posts

4.4 DESTRUCTIVE CANTILEVERED POST TESTING

All 40 old posts salvaged from both test sites were transported to FPL for further evaluation. Prior to mechanical testing, measurements of the posts included dimensions, weight, diagrams of major defects, and stress wave MOE. This information will be used to help understand the limitations of the pulse-echo acoustic evaluation technique used in the field assessments. All posts were then loaded to failure in cantilevered bending as shown in Figure 7. The testing configuration was designed to estimate the in-service guardrail system geometric conditions with the load point located 527mm from the support. LVDT deflections were measured at the loading point and near the base support. In addition, deflections were recorded at opposite, unloaded end to detect uplift. Loading was applied at a uniform rate of 8.4mm per minute until load resistance dropped below 50 percent of the maximum load. Loads were recorded using a 222kN load cell. Figure 8 shows a guardrail test being conducted at the FPL million pound test machine. At the conclusion of testing, samples were cut near the fractured zone for determination of moisture content and specific gravity.

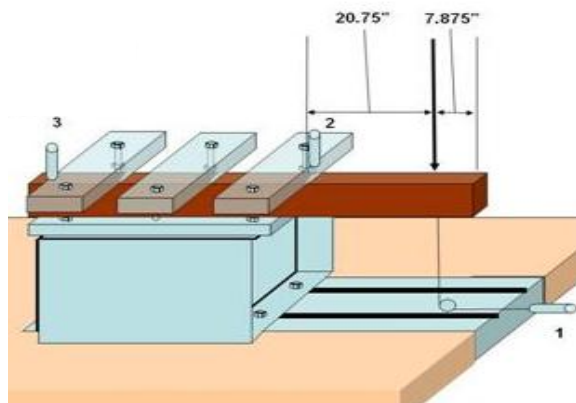


Figure 7: Cantilevered post test setup showing three numbered LVDT positions and the load point location. (20.75 in. = 527mm, 7.875 in. = 200mm)



Figure 8: Destructive testing for cantilevered post strength

Table 1: Summary of field testing of guardrail posts

Test site	Old posts		New posts	
	In ground	Out of ground	In ground	Out of ground
Royalton	20	20	20	20
Merrimac	20	20	20	17 ^a
Total	40	40	40	37

^a-three posts were damaged or lost during installation at the Merrimac test site

5 FIELD TEST SITES

Guardrail posts were evaluated at two different field sites in the state of Wisconsin as described in Table 1. The southernmost site, shown in Figure 9, is located along state highway 113 near the city of Merrimac in Sauk County. The northernmost site, shown in Figure 10, is located along state highway 54 just east of the city Royalton at the railroad overpass in Waupaca County.

Both field sites contained strong-post w-beam guardrail systems that had been in-service for several years. All guardrail posts evaluated in this study were strong-posts measuring approximately 15x20cm in cross-section. The length of the guardrail posts varied from 1.8 to 2.0m depending on embedment length. Salvaged posts were southern pine while new posts were either red or white pine, both being local softwood species in the state of Wisconsin.

5.1 EVALUATION OF OLD POSTS

5.1.1 In-Ground

Prior to removal from service at each test site, all old guardrail posts were evaluated using pulse-echo acoustic testing techniques while still embedded in the ground.

At the Royalton test site, all 20 guardrail posts were evaluated at the southeast corner approach guardrail at the railroad overpass bridge. The Royalton guardrail posts were in-service since 1996, or approximately 13 years, at the time of removal.



Figure 9: Merrimac field site showing old posts in-service

At the Merrimac test site, located north of Lake Wisconsin along state highway 113 about 2 km west of the car-ferry entrance road, 20 posts were evaluated at the northeast and southeast corner of the Gallus Slough bridge. It was unclear from documentation how long the Merrimac posts were in-service, but is likely more than 20 years based on their relative condition. At both sites, the new posts were installed by hydraulic post-driving machine.



Figure 10: Royalton field site showing old posts in-service

5.1.2 Out-of-Ground

Prior to destructive cantilever strength testing in the laboratory, all old guardrail posts were re-evaluated out-of-ground on test supports. Pulse-echo tests were repeated while other measurements of the posts included dimensions, weight, diagrams of major defects, and stress wave MOE.

5.2 EVALUATION OF NEW POSTS

5.2.1 Out-of-Ground

Prior to installation of the new posts at the field test site, all new guardrail posts were evaluated out-of-ground using similar pulse-echo acoustic techniques as shown in Figure 11. These tests were conducted in the field adjacent to the construction site. A stainless steel label was applied to each post to identify it for future inspections and/or condition monitoring.



Figure 11: Testing of new posts prior to installation at the Merrimac test site

5.2.2 In-Ground

After installation of the post and guardrail system, all new guardrail posts were re-evaluated in the ground. The Royalton test posts were installed at the northeast approach guardrail section at the railroad overpass bridge. The Merrimac test posts were installed north of the Wisconsin River along the north side of hwy 113 approximately 2 km west of the car-ferry entrance road.

6 RESULTS

6.1 PULSE-ECHO ACOUSTIC TESTING

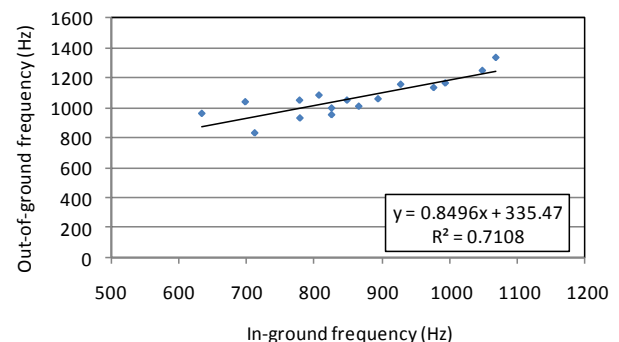


Figure 12: In-ground vs. out-of-ground comparison of FFT frequencies from the Royalton site

A comparison of results from the Royalton site is shown in Figure 12. FFT frequencies for all 20 posts in-ground and out-of-ground test conditions are compared. For most posts, the in-ground FFT frequency was proportional to the out-of-ground FFT frequency. These differences are most likely related to the different boundary conditions of soil embedment and rail hardware attachments. This data in Figure 12 (minus 3 outlier data points) shows evidence of a linear relationship ($r^2 = 0.71$) exists for predicting the out-of-ground frequency while in-service.

6.2 PARALLEL-TO-GRAIN STRESS WAVE TESTING

Results of the nondestructive testing for parallel-to-grain stress wave timings are provided. Figure 13 shows the estimated velocities for the 20 new posts at the Royalton test site. The in-ground velocities, estimated over a shorter distance, show slightly more variability than the out-of-ground velocity values. This highlights the importance of accurate distance measurements when collecting stress wave timing over short travel distances.

6.3 PERPENDICULAR-TO-GRAIN STRESS WAVE TESTING

Typical results from the nondestructive stress wave scanning of the old guardrail posts after removal from service are provided in Figure 14. These results show signs of deterioration in the above ground portion of the posts (data points 1-4) as indicated by elevated stress wave transmission rates. The above ground post condition was generally poorer, due to the presence of oxygen to promote decay activity.

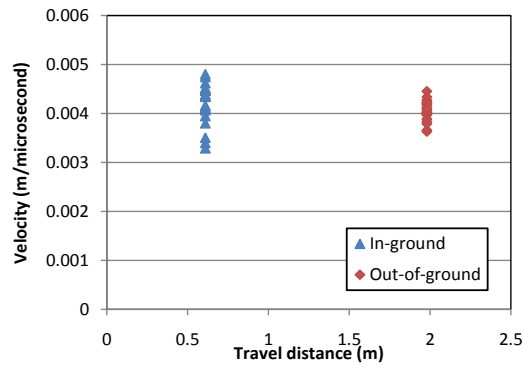


Figure 13: Sound wave velocities derived from parallel-to-grain stress wave timing at the Royalton test site

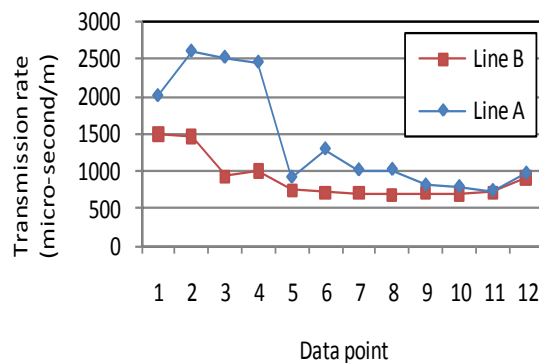


Figure 14: Typical results from perpendicular-to-grain stress wave scanning

6.4 LABORATORY STRENGTH TESTING

Results of the cantilever bending strength testing of the salvaged guardrail posts from the Royalton site are provided in Figure 15. Modulus of rupture values varied over a wide range from 6 to 30 MPa. Some of the lower strength values were affected by the presence of lumber defects in the fracture zone.

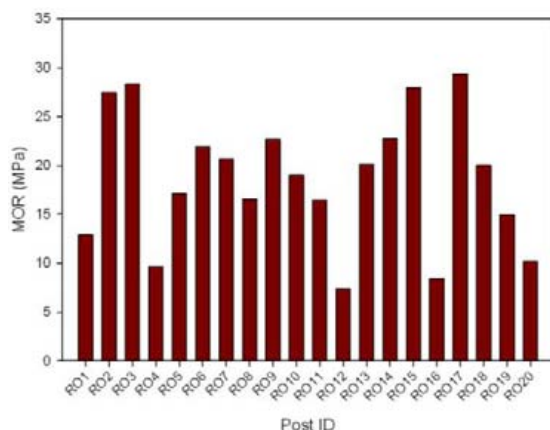


Figure 15: MOR values of the Royalton test posts

7 CONCLUSIONS

This study evaluated 20 guardrail posts from two field sites in the state of Wisconsin. Nondestructive pulse-echo acoustic testing was performed on the guardrail posts while in-service to record their acoustic response. Destructive testing was performed in the laboratory to determine cantilever bending strength. The preliminary results included demonstrate that pulse-echo acoustic testing protocol shows promise as a reliable predictor of guardrail post integrity. Further data analysis is currently underway. The overall goal is to provide inspectors with a reliable and practical diagnostic tool for in-service guardrail assessments.

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