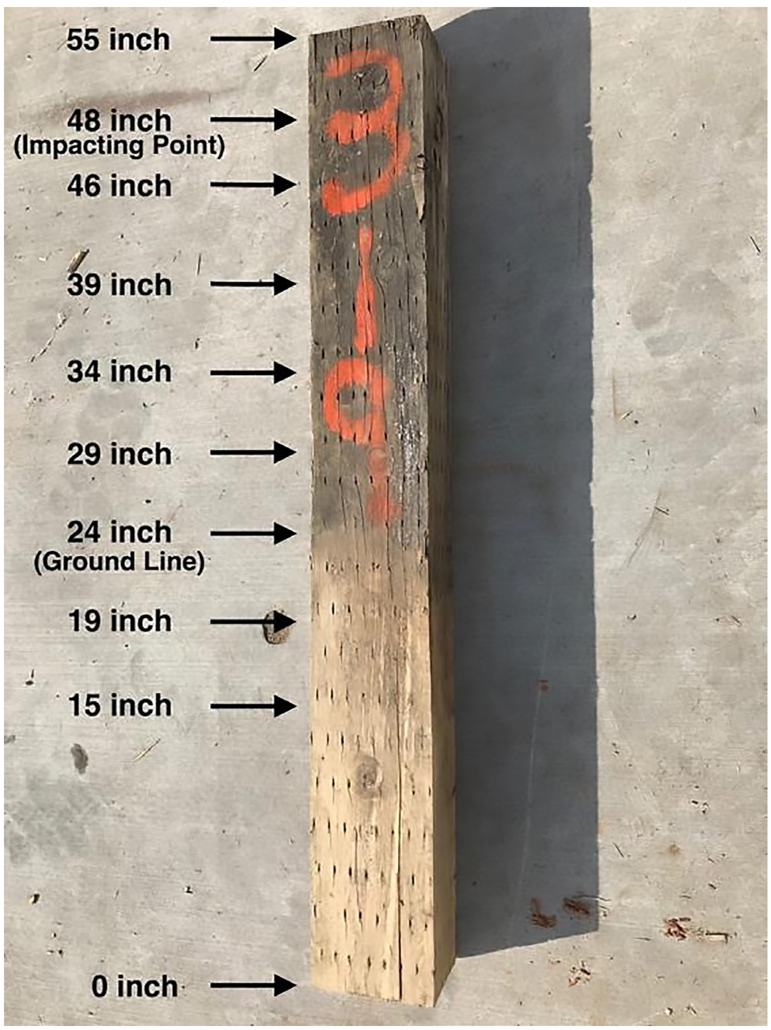
Field Analysis of Wood Guardrail Post Decay

WA-RD 890.1

Adam R. Phillips
Qiyang Luo

December 2018



Washington State Department of Transportation

Office of Research & Library Services

WSDOT Research Report

19-02-0119

Research Report

Research Project T1462, Task 16

FIELD ANALYSIS OF WOOD GUARDRAIL POST DECAY

by

Adam R. Phillips and Qiyang Luo
Department of Civil and Environmental Engineering
Washington State University
Pullman, WA 99164

Washington State Transportation Center (TRAC)
Washington State University
Room 101, Sloan Hall, WSU Campus
Pullman, WA 99164

Washington State Department of Transportation
Technical Monitors
Brad Manchas and John Donahue
Highway Design and Safety

Prepared for

The State of Washington **Department of Transportation**

Roger Millar, Secretary

December 2018

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENTS CATALOG NO.
WA-RD 890.1		

4. TITLE AND SUBTITLE	5. REPORT DATE
Field Analysis of Wood Guardrail Post Decay	December 2018
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Adam R. Phillips and Qiyang Luo	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Washington State University Department of Civil and Environmental Engineering Pullman, WA 99164-2910	
	11. CONTRACT OR GRANT NO.

12. SPONSORING AGENGY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Washington State Department of Transportation Research Office Olympia, WA 9850-7372	Final Research Report
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Wood guardrail posts can be inspected for decay using a non-destructive testing (NDT) technique called stress wave timing (SWT). This project conducted a field investigation on approximately 500 wood guardrail posts using SWT and then analyzed available data to determine factors that may lead to increased wood decay rates. It was determined that locations with high climate index (> 40) were experiencing higher decay rates. Additionally, poor preservative retention levels were also found to be associated with high decay rates. Impact testing concluded that decay reduces the fracture resistance of wood posts by more than 50%. The results of this report will be useful in considering approaches to managing WSDOT guardrail assets in the future.

17. KEYWORDS	18. DISTRIBUTION STATEMENT
Nondestructive Testing (NDT), Stress Wave Timing (SWT), Wood, Guardrail, Pendulum Impact Testing, Fracture Energy	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	55	

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation, Federal Highway Administration, or U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation.

Table of Contents

List of Tables

List of Figures

Executive Summary

The previous project, finished in 2015 by Olszko and Bender, identified stress wave timing (SWT) as the optimal non-destructive testing technique for field inspection of timber guardrail posts. In conjunction with a local industrial firm, Metriguard, Inc., a SWT prototype was built and delivered to WSDOT. One of the recommendation of the previous study was to field trial the new SWT device and determine an effective inspection strategy for guardrail systems.

This project started with the field investigation of 498 guardrail posts in five regions of Washington State; four along the western coast and one in the south central part of the state. The field inspections revealed an overall decay rate of approximately 25%, but the western regions had the majority of the decayed posts (up to 37% in one region) and the central region had a low decay rate of 5%. The 126 decayed posts located during field inspections were removed from service and delivered to Washington State University for additional testing and analysis.

Further analysis investigated factors that could lead to higher rates of decay. It was determined that the posts inspected were most likely of the Hem-fir grouping and were in service approximately 23 - 28 years. Neither post age nor species grouping could be strongly linked to increased rates of decay. The strongest factor that predicted high decay rate was climate index, which is a measure of a regions average annual rainfall and

temperature. Three of the four regions with climate index greater than 40 had decay rates near or above 30%.

Material and preservative treatment testing was conducted at Oregon State University and determined that the preservative penetration depth was within the AWPA standard of 10mm for all sample posts. Preservative retention however was lower than the AWPA standard for approximately 70% of the sample posts. It is likely that poor preservative retention could have been a factor in the high decay rate.

Lastly, pendulum impact tests were conducted on 15 posts with varying levels of decay. The pendulum was 3,800 lbs and impacted the posts at approximately 9.2 mph. It was determined that decay significantly decreases the posts impact resistance, as measured by fracture energy. Decayed posts with SWT velocities at the ground level less than 20 in./μs had 50% less fracture energy than posts with SWT velocities at the ground level greater than 38 in./μs.

The results of the field and laboratory studies demonstrate that SWT is capable of identifying posts with internal decay. Additionally, it was recommended that SWT test results can be useful in considering the role of post decay in an asset management strategy. A recommendation was also made to specify UC4C (extreme duty) treatment category for newly acquired batches of treated timber posts in areas with climate index greater than 60, due to the high decay risk and severe service conditions. Treatment category UC4A (general use for ground contact) should be specified for all other newly acquired batches of treated timber posts based on AWPA standards. Lastly, it was recommended that newly acquired batches of treated timber posts be inspected by an ALSC accredited agency and have the standard quality control mark to ensure that preservative penetration and retention levels meet the AWPA specified minimums for their respective treatment category.

Introduction

Guardrail systems reduce the risk to motorists involved in roadway departure crashes by dissipating the impact kinetic energy and keeping the vehicle from leaving the roadway. The guardrail post is an important part of the overall guardrail system and is intended to rotate in the soil during a collision. Therefore, guardrail posts need sufficient strength and fracture resistance so that they do not break upon impact prior to rotation in the ground.

Wood guardrail posts, which are widely used throughout Washington (~1.5 – 2 million on state highway system), can be susceptible to decay and deterioration, which could weaken their impact resistance. Wood decay is due to fungal growth, which is commonly located inside the post, or insect intrusion and is difficult to detect using only visual inspection. Phase I of this research (discussed further in "Review of Previous Work") proposed utilizing a stress wave timing (SWT) device for non-destructive field testing of wood posts. The SWT device detects wood decay using the difference in sound wave speed as measured through decayed vs intact wood.

This project further validated the SWT device for guardrail post inspection by conducting a field evaluation study on almost 500 in-situ posts in western and central Washington. SWT was compared to traditional inspection methods and minimally invasive inspection methods. Following the field inspections, the decayed timber posts that were located were removed from service and sent to Washington State University (WSU) for further analysis and investigation. Variables such as the posts location, climate, species, and treatment were analyzed to determine any correlations to high decay rates. Lastly, a sample of the posts were tested under dynamic impact to determine decay's effect on the impact resistance of the posts.

The various investigation results presented in this report can inform the design of testing protocols that would assist WSDOT in determining whether timber guardrail posts may remain in service. Information about the characteristics correlated with higher rates of decay can be used to inform the design of inspection program in possible problem areas. Finally, the study provides further verification that SWT is the best non-destructive testing method available for field inspection of timber posts.

Review of Previous Work

There is a long history of literature available on inspection of wood guardrail posts and the effects of wood deterioration on performance. To supplement the results of this study, technical literature is presented below. The previous WSDOT study, "Identification of Test Methods for Determining Wood Guardrail Post Integrity", is reviewed to lay the groundwork from which this study builds (Olszko and Bender 2015). Additionally, literature related to the fundamentals of stress wave timing, inspection methods, decay classifications, and wood post performance is also reviewed.

Olszko and Bender WSDOT Study

In Phase I of this study, Olszko and Bender (2015) determined that stress wave timing (SWT) was the best NDT option for field analysis of wood guardrail posts. SWT measures the transit time of a stress wave as it travels from a transmitter to a receiver, often known as a pitch-catch or time-of-flight setup. The physics of SWT is described by the relationship shown in Equation 1, where L is the travel distance, t is travel time, E_D is the dynamic modulus of elasticity, g is the gravitational constant, and γ is the material density. Sound, non-deteriorated, wood results in a faster transit time than decayed wood. For more information on SWT refer to Ross and Pellerin (1994), Hoyle and Pellerin (1978), Emerson et al. (2002), and Brashaw et al. (2005). Phase I of this study delivered a SWT device, produced by Metriguard Inc., to WSDOT.

$$\frac{L}{t} = \sqrt{\frac{E_D g}{\gamma}} \tag{1}$$

Olszko and Bender (2015) also discussed another form of inspection, drilling, that may be more accurate than visual inspection, but less expensive than SWT. This method is minimally invasive because it involves drilling into the specimen; whereas SWT is non-destructive. Drilling, or resistograph testing, uses a device that measures torque to judge the resistance of the wood. Higher torque resistance indicates sound wood, while low or no torque resistance indicates unsound wood. Olszko and Bender (2015) produced a prototype drilling devices using long partially threaded screws, as shown in Figure 1.

Figure 1. Drill bit used for checking decay created from a FastenMaster Headlok HLGM010 fastener. (Olszko and Bender 2015)

Lastly, Olszko and Bender (2015) conducted destructive pseudo-static bending tests on posts with no decay, moderate decay, and severe decay to compare the flexural capacity to the AASHTO standard for guardrail posts of 8.2 MPa (1,190 psi). Of the 193 posts tested to failure, only 9 failed to meet the AASHTO minimum and they were all classified as severely decayed. Furthermore, 24 posts with severe decay and all 33 posts with moderate decay passed the AASHTO minimum specification. This is because when the member is loaded slowly in bending, the outermost fibers, which are usually sound in treated posts, resist the majority of the load.

Deterioration Classification and Effects on Performance

Recent work by Plaxico and Ray (2015) has examined how guardrail systems perform during a crash event if the guardrail posts have deterioration. However, that study focuses mostly on the behavior of the guardrail system and not the *in situ* inspection techniques necessary to determine the level of deterioration. The models and conclusions developed by Plaxico and Ray (2015) may be utilized to determine the effect of post strength loss on the overall guardrail system strength loss.

Post Response to Dynamic Impact

Previous studies have investigated the influence of timber post decay on the impact resistance of the posts (Gabauer et al. 2010, Plaxico and Ray 2015, Plaxico et al. 1998). A 1988 study conducted by the Southwest Research Institute for Michigan DOT examined the suitability of different timber species for guardrail posts (Hancock and Mayer 1988). The study focused on grading and the necessary pendulum fracture energy needed to correspond to safe crash tests of new posts. Hancock and Mayer (1988) determined that posts with less fracture energy than 6.0 k-ft. are not suitable for strong-post guardrail systems. Plaxico and Ray have conducted extensive pendulum impact testing and finite element modeling of timber posts with and without decay for Midwest and Northeast guardrail systems. The posts tested by Plaxico and Ray were cylindrical in shape and were tested using a 2,372 lb. rigid pendulum impacting at 10 mph at a height of 21.5 inches above the ground (Plaxico and Ray 2015). Gabauer et al. (2010) described how pendulum impact testing can be an effective means for determining the crash performance of not only the guardrail posts, but also the entire longitudinal barrier systems. The Gabauer et al. (2010) pendulum impact tests were conducted using a 4,508 lb. pendulum impacting at 20 mph. The Hancock and Mayer (1988) tests utilized a 4,000 lb. pendulum impacting at 9.2 mph.

Research Approach and Procedures

This project focused on field validation of SWT as the optimal inspection method for determining wood guardrail post decay, quantifying the factors that affect wood post decay in the Northwest, and determining the effects of wood decay on guardrail post impact resistance. Field inspection of 498 posts was conducted utilizing four methods of inspection: visual evaluation, sounding, drilling (minimally invasive), and SWT, and then compared for accuracy relative to SWT. Following the field inspection, 126 of the decayed posts located during inspections were removed from service and sent to WSU for further analysis and testing. Factors such as Scheffer climate index, post age, post species, post treatment type, preservative penetration, and preservative retention were examined to determine which may correlate with higher rates of decay. Lastly, several of the posts were testing using a pendulum impact device to determine how decay influences the posts reaction to dynamic impact.

Field Validation of Inspection Procedures

Five geographic regions were targeted for field inspection based on WSDOT's recommendations and a Scheffer Decay Hazard Index map, shown in Figure 2. Four of the regions are located on the western coast of Washington, which is the wettest part of the state based on annual precipitation data. One region, Wishram, was used as a baseline measurement for comparison and was assumed to be similar to the rest of the state east of the Cascade mountain range, where annual precipitation is much lower. Figure 2 also shows the number of field inspections that were conducted in each region.

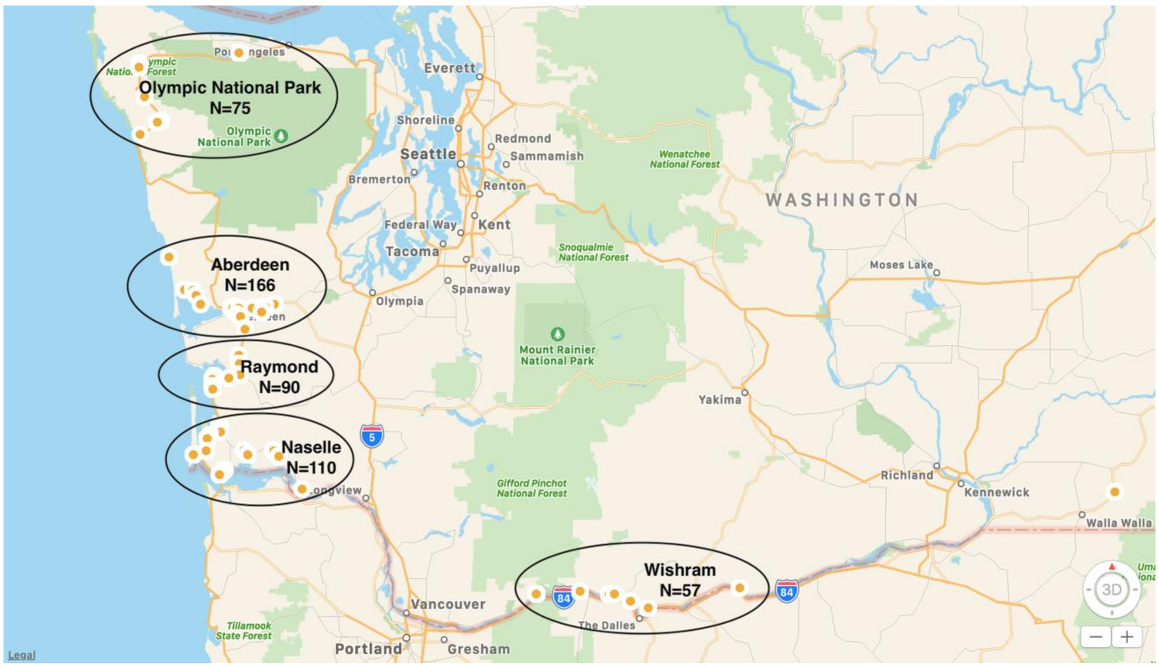


Figure 2. Timber post inspection regions

<u>Field Inspection Procedure</u>

All the field inspections were conducted with an identical procedure to determine the efficacy of each inspection method. The four inspection methods used were visual inspection, sounding with a standard framing hammer, drilling with the Olszko and Bender (2015) drill bit, and SWT using the MetriGuard device. The inspection procedure followed was:

1. Visual inspection for decay or deterioration, make note of condition
2. Sounding with standard hammer on area of post between ground level and 15 in. above ground level. If post sounds hollow or if hammer significantly crushes wood note as deteriorated.
3. Inspect with drill bit as close to ground level as possible. If bit spins freely without resistance note as deteriorated.
4. Inspect with SWT device at 12” above ground level and then at ground level.
    a. If measurements are more than 20% different, note as deteriorated
    b. If either measurement is below 30 in./sec., note as deteriorated

Deteriorated posts were marked with orange fluorescent paint for WSDOT to remove from service. As far as authors are aware, all deteriorated posts located during field testing were removed from service and sent to WSU for further analysis.

Analysis of Factors Influencing Post Deterioration

Several factors that could affect post decay were evaluated using the field inspected sample of 498 posts. The factors investigated were the post’s age, climate index, timber species, treatment preservative penetration, and preservative retention. The influence of post age was difficult to determine due to limited data on when the posts were installed in the field. It is believed that many of the posts were installed at approximately the same time between 1990 and 1995. Therefore, since age was relatively constant across the inspection regions it cannot be determined if it is a factor causing higher rates of decay. However, it is worth noting that the posts inspected were approximately 20-25 years old and had an overall decay rate of approximately 25%.

Scheffer Climate Index

The Scheffer climate index was used to capture the influence of the posts location on decay. Scheffer climate index combines annual precipitation data with temperature data to determine an aggregate score (index) that describes how wet, hot, and humid a place is on a scale roughly from 0 to 100 (Scheffer 1972). The equation for calculating climate index (*CI*) is provided below (Equation 2) where *T* is the mean monthly temperature (° F) and *D* is the mean number of days in the month with 0.01 inch or more of precipitation. The sum of the months is arbitrarily divided by 30 to make the index roughly fall within 0 to 100 for the United States.

$$CI = \frac{\sum_{Jan}^{Dec}[(T-35)(D-3)]}{30} \qquad (2)$$

Data for monthly temperature and precipitation was found using the *National Center for Environmental Information* website for multiple locations within each inspection region (NOAA).

Wood Species and Treatment

The wood species and treatment was difficult to track down using WSDOT installation records. Therefore, a sample of 15 decayed posts were taken from the overall sample of 126 decayed posts and sent to Dr. Jeff Morrell at Oregon State University for preservative analysis and fungal culturing. The small sample of 15 posts includes three posts from each of the five inspection regions to provide a broad geographical distribution.

The preservative analysis was conducted by visually assessing the preservative penetration depth to the nearest millimeter (mm) and through chemical assay on the outer 10mm zone of each sample (Cappellazzi and Morrell 2018). The 10mm sample was ground to pass a 20 mesh sieve and analyzed using a Spectro-Titan-X-ray-flourescence-analyzer. Results were compared to treatment American Wood Protection Association (AWPA) Standards for either chromated-copper-arsenate (CCA) or pentachlorophenol (Penta).

Decayed Post Performance to Dynamic Impact

To determine the reduction in impact resistance due to wood decay, a series of pendulum impact tests were conducted on 15 of the decayed posts recovered from the field inspections. The pendulum impact tests were conducted in a similar method as Hancock and Mayer (1988), Gabauer et al. (2010), and Plaxico and Ray (2015). The pendulum test apparatus constructed at Washington State University is shown in Figure 3. The pendulum weight was approximately 3,800 lb., had a swing radius of 9 ft., and impacted the post at a velocity of approximately 13.4 fps (feet/sec.), or 9.13 mph, at a height of 24 in. above the ground level. As the objective was to quantify the fracture energy of the posts rather than soil characteristics, the posts were fixed at the base using a stiff steel sleeve. The post holder was located so that the impact would occur at the lowest point of the pendulum arc, where the kinetic energy of the mass was greatest.

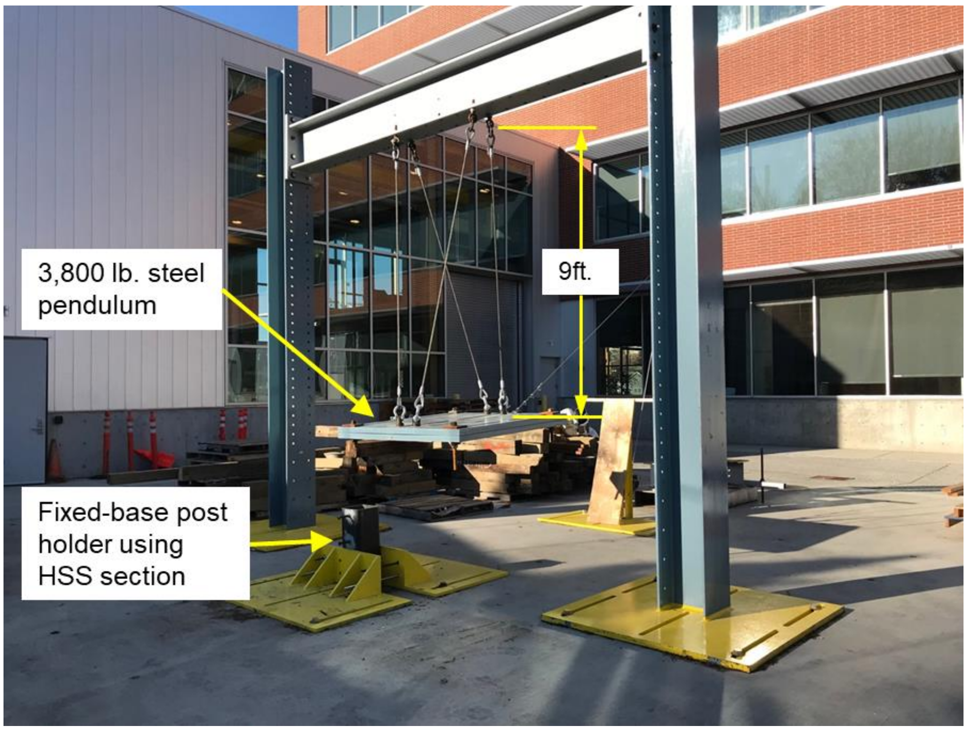


Figure 3. Pendulum test apparatus

The pendulum data was recorded using a three-axis accelerometer mounted on the top face of the pendulum, shown in Figure 4. The pendulum did not swing out-of-plane, along the y-axis, and therefore only acceleration along the x-axis and z-axis were used for data analysis. The accelerometer recorded measurements using fixed local coordinates along the device's x-axis and z-axis, with the local x-axis being in the tangential direction of the swing arc and the local z-axis being in the radial direction of the swing arc. The local coordinate acceleration data (radial and tangential) was transformed to global Cartesian coordinates using a transformation matrix, shown in Equation 3, where capital letters denote global coordinates and lower case letters denote local coordinates.

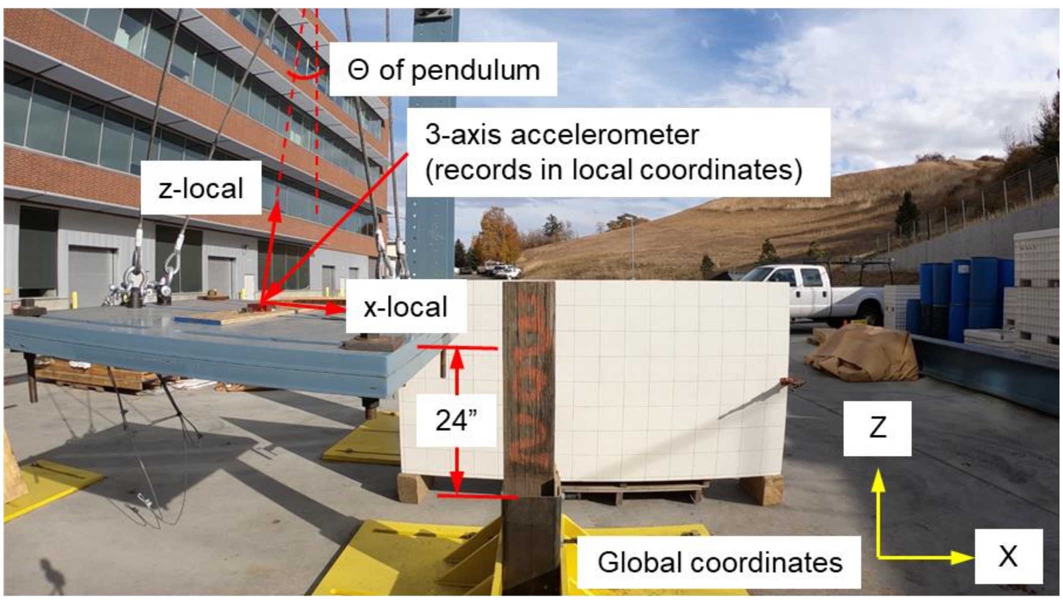


Figure 4. Instrumentation of pendulum using accelerometer

$$\begin{bmatrix} A_Z \\ A_X \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} a_z \\ a_x \end{bmatrix} \quad (3)$$

Prior to testing the first guardrail post specimen, free vibration tests were conducted to validate the instrumentation, data analysis methods, and compare the recorded pendulum motion to the theoretical dynamics solution assuming small angles of theta and a constant radius, r. Equation 4 is the solution to the differential equation of pendulum motion in polar coordinates, where θ_{max} is the initial angle (Equation 5) and ω is the pendulum natural frequency of vibration (Equation 6). The polar coordinates solution can then be transformed into global Cartesian coordinates for the x-axis displacement, shown in Equation 7, and differentiated once to solve for the global x-axis velocity (Equation 8) and twice for the global x-axis acceleration (Equation 9)

$$\theta = \theta_{max}\cos(\omega t) \tag{4}$$

$$\theta_{max} = \sin^{-1}\left(\frac{x_i}{r}\right) \tag{5}$$

$$\omega = \sqrt{\frac{g}{r}} \tag{6}$$

$$U_x = r\sin(\theta) \tag{7}$$

$$V_x = r\cos(\theta)\,\dot{\theta} \tag{8}$$

$$A_x = r\cos(\theta)\,\ddot{\theta} - r\sin(\theta)\,\dot{\theta}^2 \tag{9}$$

The highest impact velocity possible at the WSU testing facility was 13.4 fps, or 9.13 mph, which is nearly identical to the velocity used during the Hancock and Mayer tests (1988). To achieve that velocity the pendulum initial angle, θ_{max}, was approximately 50 degrees (0.87 radian), which violates the small angle assumption. However, this violation does not create a large error for the first half-cycle of the pendulum motion, as shown by Figure 5. Figure 5 shows the theoretical global x-displacement, U_x, and x-velocity, V_x, versus the recorded pendulum free-vibration response. The error between the theoretical and test peak velocities (impact velocities) was 2.6% and the error between the theoretical and test peak negative displacements was 1.8%. The first half-cycle of the motion is all that is important for the impact tests because at one-quarter cycle (acceleration = 0 and velocity = max) the pendulum will impact the post and the deceleration of the pendulum up to its peak negative displacement (velocity = 0) is what will be utilized to calculate the fracture energy of the posts.

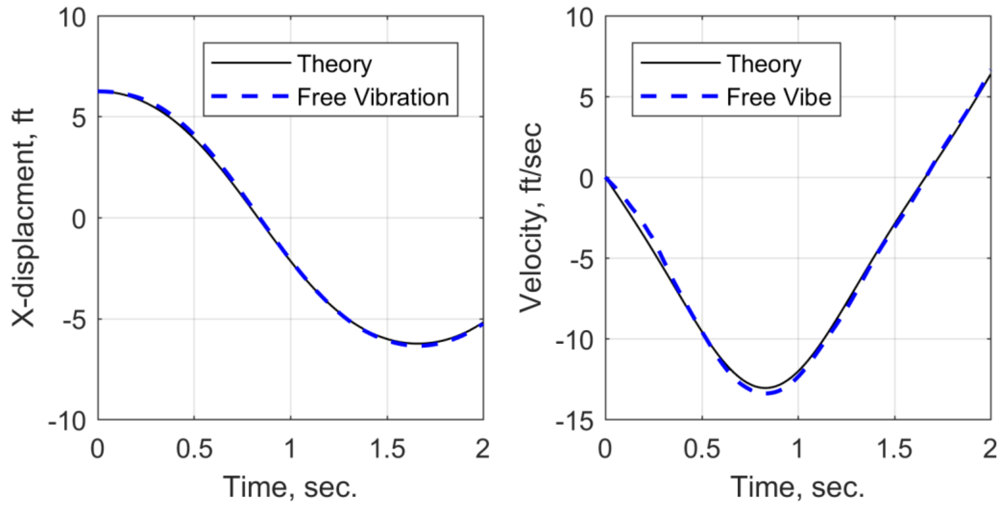


Figure 5. Velocity comparison between free vibration and theory

The pendulum velocity and displacement were calculated by transforming the accelerometer data from local coordinates to global coordinates, using Equation 3, then numerically integrating the global x-acceleration, A_x, to solve for global x-velocity, V_x, and integrating x-velocity to solve for x-displacement, U_x. Integration was conducted using the trapezoidal rule. Since the pendulum arm was not rigid in reality, but instead four high-strength cables, there was significant noise in the local z-acceleration data immediately following pendulum release that would have negatively impacted the numerical integration. To fix this, the values of z-acceleration for the first 0.25 seconds of the pendulum motion were corrected to envelope the bottom of the recorded response, shown in Figure 6. This does not affect the data recorded at impact (t = 0.84 sec.) or data recorded after, but improves the accuracy of the data analysis.

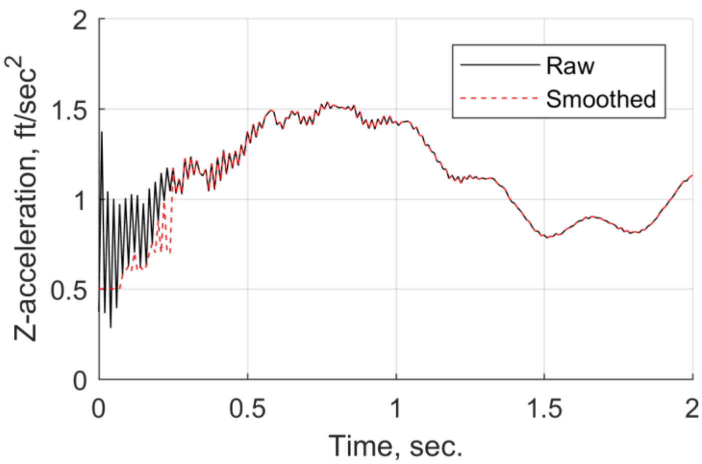


Figure 6. Correction to local z-acceleration data

Prior to testing, the fifteen test specimens were cut to the same length of 48 in. such that the ground level (GL) of each post would lie at the top of the post holder, placing the decayed region of the post at the location of highest bending moment. Each specimen was then re-evaluated using the SWT device at several locations along the height, as summarized in Table 1 and shown by Figure 7. The laboratory SWT results were compared to the field testing results and approximately half (7 of 15) had more than a 20% difference between the field and laboratory lowest SWT velocity (shown with italics text in Table 1).

Table 1. Laboratory SWT testing results compared to field results of fifteen impact test specimens

		Field Testing		**Laboratory Testing**	
Post #	**Post Location****	**High SWT velocity (in./µs)**	**Low SWT velocity (in./µs)**	**High SWT velocity (in./µs)**	**Avg. SWT velocity at GL (in./µs)**
282	*Naselle*	*48.5*	*29.4*	*36.3*	*9.6*
319	Naselle	166.0*	13.7	35.3	16.9
302	Naselle	46.3	20.0	57.2	21.2
42	Aberdeen	44.9	16.6	51.0	17.7
291	*Naselle*	*44.3*	*15.2*	*63.0*	*28.6*
293	Naselle	29.3	18.9	36.1	17.8
254	*Aberdeen*	*21.2*	*11.8*	*54.1*	*34.5*
24	Aberdeen	68.6	51.9	51.6	46.4
66	Aberdeen	44.0	19.8	45.3	24.3
418	*Naselle*	*46.3*	*11.1*	*48.2*	*36.5*
33	Aberdeen	33.7	23.5	33.6	26.8
86	Aberdeen	50.6	49.9	55.6	42.0
300	*Naselle*	*55.3*	*53.1*	*41.2*	*29.5*
83	*Aberdeen*	*51.5*	*39.4*	*65.5*	*31.1*
99	*Raymond*	*54.2*	*31.2*	*75.8*	*51.4*

* Value seems too high and is probably a false SWT velocity.

** Italics indicate posts where field and laboratory SWT inspection yielded different results by more than 20%

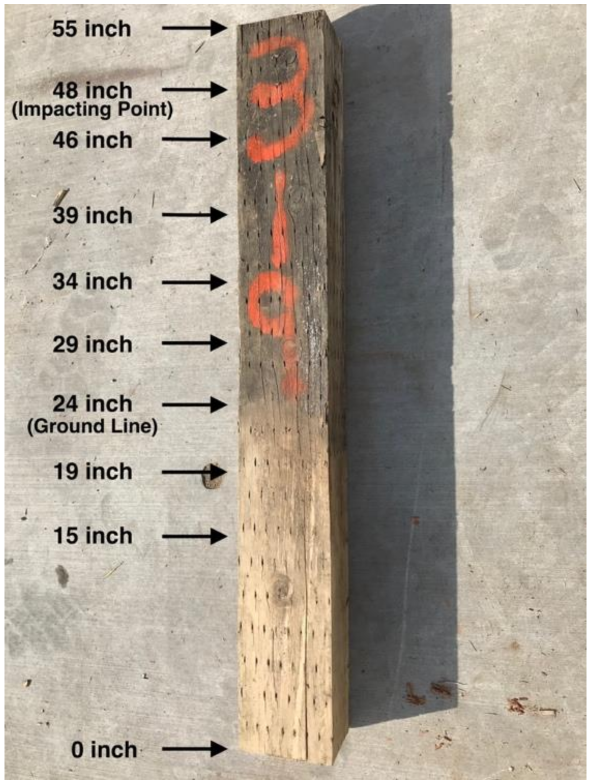


Figure 7. Specimen preparation and SWT testing locations (Post 319)

The impact testing acceleration data was utilized to calculate the fracture energy (FE) of the guardrail post using two different methods. For either method, the recorded acceleration was first processed as described above and the global x-axis acceleration, velocity, and displacement was calculated. The first method calculates fracture energy as the change in kinetic energy, shown by Equation 10, where m is the mass of the pendulum, v_f is the final velocity after impact, and v_o is the impact velocity (Hancock and Mayer 1988). Figure 8 graphically shows the final and impact velocities using the Post 83 experimental data.

$$FE_k = \frac{1}{2}m\left(v_f^2 - v_o^2\right) \quad (10)$$

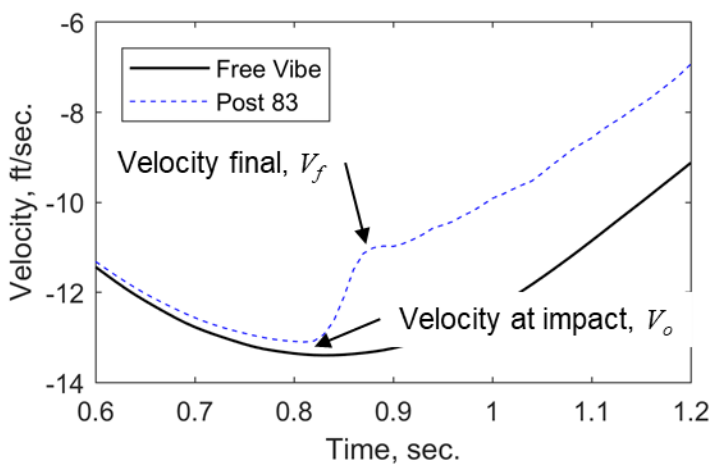


Figure 8. Example of initial and final velocities for FE calculation using kinetic energy

The second method calculates fracture energy based on conservation of energy principles at the peak negative displacement of the pendulum. Equation 11 shows that fracture energy can be calculated by subtracting the potential energy remaining in the pendulum at the peak negative displacement after impacting a post from the potential energy of the pendulum at the peak negative displacement under free vibration. The height of the pendulum in the direction of gravity, *h*, can be calculated through geometry using Equation 12. Between the free vibration test and the impact tests, only one variable could account for the difference in potential energy and that is the energy lost due to fracture of the posts. Figure 9 shows the peak negative displacement of Post 83 versus the free vibration experiment. The two fracture energy calculation methods are discussed further in the next section, as each has pros and cons that can be shown by the test data.

$$FE_p = E_{p,free} - E_{p,post} = mg\left(h_{free} - h_{post}\right) \tag{11}$$

$$h = r - \sqrt{r^2 - u_x^2} \tag{12}$$

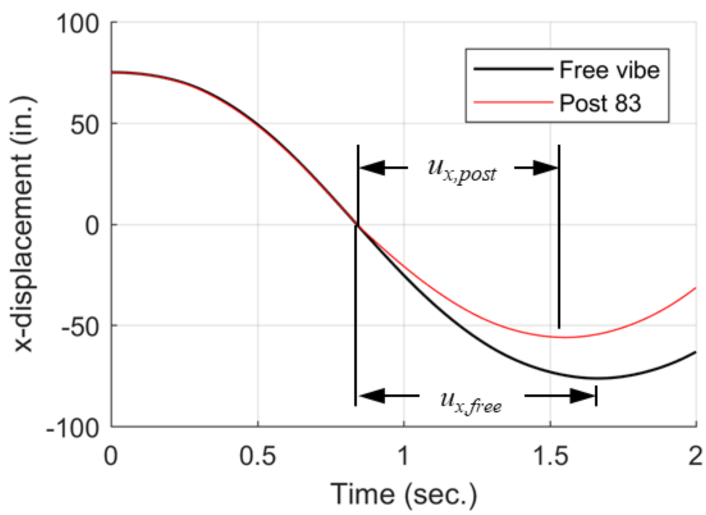


Figure 9. Example of peak x-displacement, u_x, for FE calculation using potential energy

Findings and Discussion

Discussion of the research findings are divided into the three major objectives of the project: 1) field validation of inspection methods to determine wood guardrail post decay, 2) quantifying the factors that affect wood decay in the Northwest, and 3) determining the effects of wood decay on guardrail post impact resistance.

Validation of SWT Inspection Method

The four inspection methods were compared to determine the accuracy of each method relative to SWT. It was assumed that stress wave timing (SWT) was 100% accurate at determining if a post was deteriorated based on the previous Olzsko and Bender (2015) study. Table 2 shows the results of the comparative analysis and it clearly shows that SWT is the best option for field inspection. The drilling method was the next best, but only found 89% of the decayed posts compared to the SWT. Sounding found 87.5% of the decayed posts, which is relatively good for the simplicity of the method. However, it should be noted that all inspections were conducted in summer on clear days, therefore the posts were relatively dry. Wet posts will have a different sound that can sound hollow, giving a false reading. Visual inspection only found 82% of the decayed posts and therefore should not be used a primary inspection method.

Table 2. Inspection methods effectiveness relative to stress wave timing

Inspection Method	Number of Found to be Decayed	Efficacy Relative to SWT
Stress Wave Timing (SWT)	126	100.0%
Visual	104	82.5%
Sounding	110	87.3%
Drilling[1]	113	89.7%

[1] Using drill bit developed in Olzsko and Bender (2015).

Factors Correlated to High Rates of Decay

The overall decay rate of the 498 posts inspected was approximately 25%, calculated as the number of deteriorated posts found divided by the number of posts inspected. While this rate is high it should be noted that the regions provided by WSDOT for inspection were selected because they were both in decay prone areas (based on prior WSDOT experience) and over 20 years old. Therefore, this decay rate may not represent the decay rate of timber guardrail posts for the rest of the state. Factors influencing the decay rate were investigated and are described in the following sections.

Decay Rate by Inspection Region (Climate Index)

The decay rate of the inspected posts can be further classified by inspection region (shown in Figure 2), presented in Table 3. The Raymond and Naselle regions had the highest decay rates of approximately 38% and 33%, respectively. The Olympic National Park and Wishram regions had the lowest decay rates of approximately 8% and 5%, respectively. Scheffer climate index was used to quantify the environmental conditions in each region and was calculated as the average climate index for the posts located in that region. Figure 10 presents the decay rate for each region and Figure 11 shows the decay rate for each region versus climate index.

Table 3. Decay rate classified by inspection region

Region	Number of Inspected Posts	Number of Decayed Posts	Decay Rate (%)	Climate Index
Olympic National Park	75	6	8.0	63.2
Aberdeen	166	47	28.3	67.0
Raymond	90	34	37.8	65.6
Naselle	110	36	32.7	72.0
Wishram	57	3	5.3	28.9
TOTAL	498	126	25.3 (avg.)	

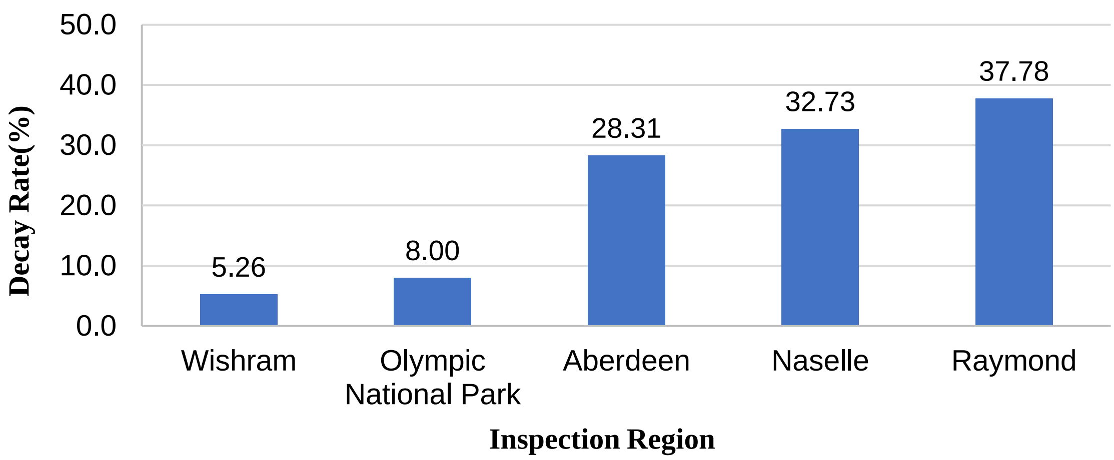


Figure 10. Decay rate for inspection regions

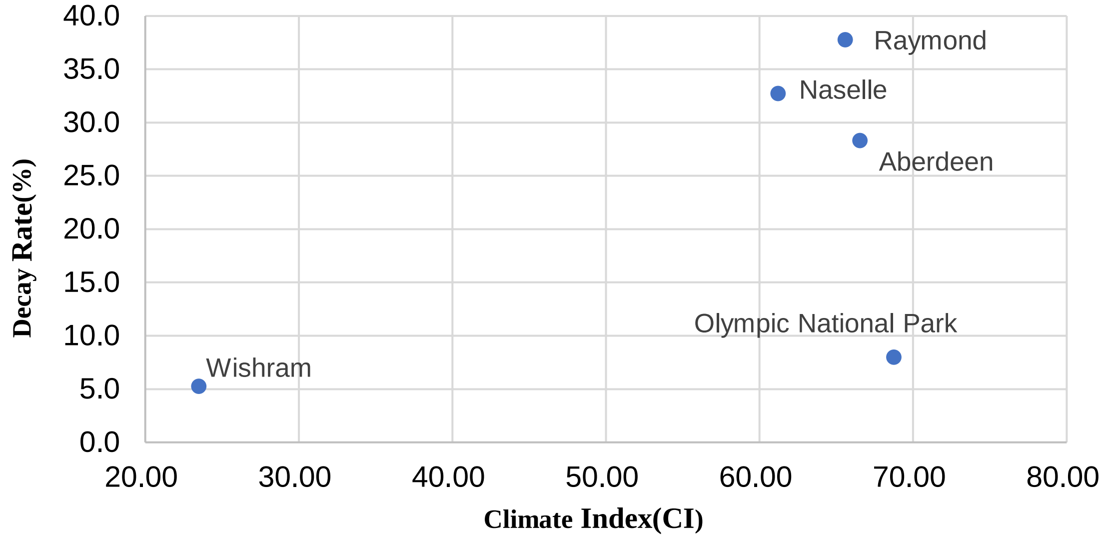


Figure 11. Decay rate versus climate index for inspection regions

Figure 11 clearly shows that the regions with higher climate index (CI) had significantly higher rates of decay. To understand more about the relationship between the climate index and wood post decay, the individual posts SWT velocity at the ground level (GL) were plotted versus the climate index of their location, shown in Figure 12. Based on the SWT Equation 1, a wave velocity for sound Hemlock was calculated to be approximately 38 in./µs, using the AWC/ANSI *National Design Specification* value for density and modulus (AWC 2015). For values of CI less than 40 only a handful of posts fell below the sound wood velocity of 38 in./µs, whereas for values of CI above 60 approximately 40% of the posts had velocities below 38 in./µs.

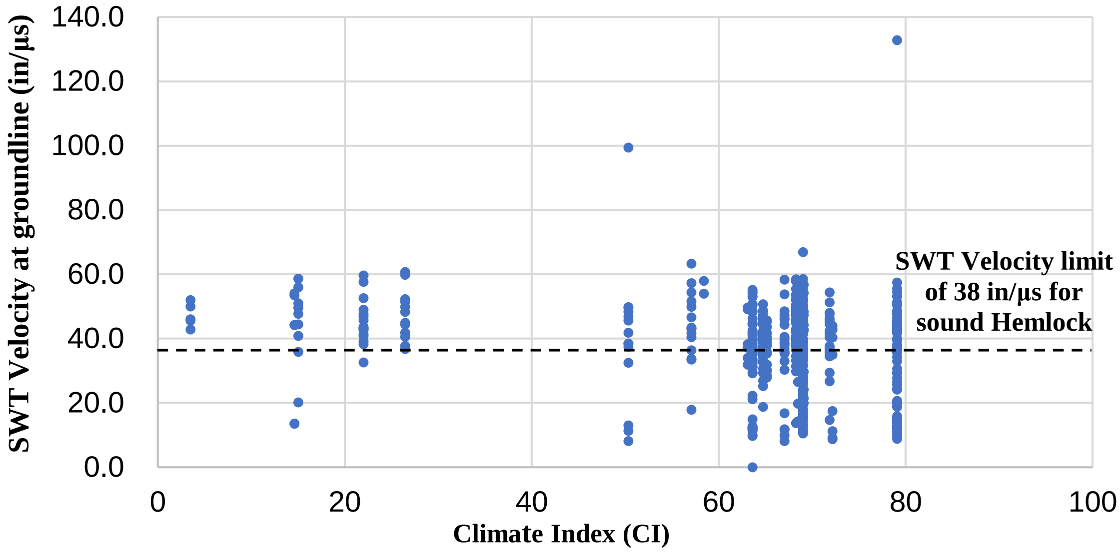


Figure 12. SWT velocity at the ground level versus climate index for field inspection sample

<u>Treatment of Decay Post Sample</u>

The data in this section was gathered from the 15 decayed posts sent to Oregon State University for species identification and preservative treatment analysis. All posts appeared to be Hem-fir, based on the gradual latewood transition and absence of normal resin canals (Cappellazzi and Morrell 2018). Since there was a wide variation in sample post location, yet no variation in species, it is assumed that the majority of posts inspected and in service in Washington State are also Hem-fir.

The preservative treatment analysis revealed that two posts were treated with Penta and the remainder were treated with CCA. The preservative penetration ranged from 10.3mm to 35.1mm and all samples exceeded the minimum penetration level of 10mm as specified by the American Wood Protection Association Standard U1 (AWPA 2017). However, the preservative retentions were generally low compared to the AWPA Standard. The retentions ranged from 1.86 kg/m^3 to 10.08 kg/m^2, but only 4 of the 15 samples met the minimum retention of 8.0 kg/m^3 set by the AWPA, as summarized in Table 4. While it is difficult to determine if the majority of the posts inspected had unsatisfactory preservative retention, the analysis results do suggest that poor preservative treatment quality could have played a role in the high rates of decay. Previous studies have shown that the incidence of internal decay increases as the quality of the preservative treatment declines (Love et al. 2014, Sinha et al. 2015).

Based on discussions with Dr. Jeff Morrell, it is not expected that the CCA or Penta treatment leached into the soil during service life resulting in low retention at the time of testing. Rather, it is more likely that the guardrail posts had unsatisfactory preservative retention at the time of installation due to poor quality control measures taken by the wood treatment facility. This knowledge is based on Dr. Morrell's previous research for Oregon Department of Transportation.

Table 4. Preservative treatment levels and presence of decay fungi in guardrail post sections (Cappellazzi and Morrell 2018)

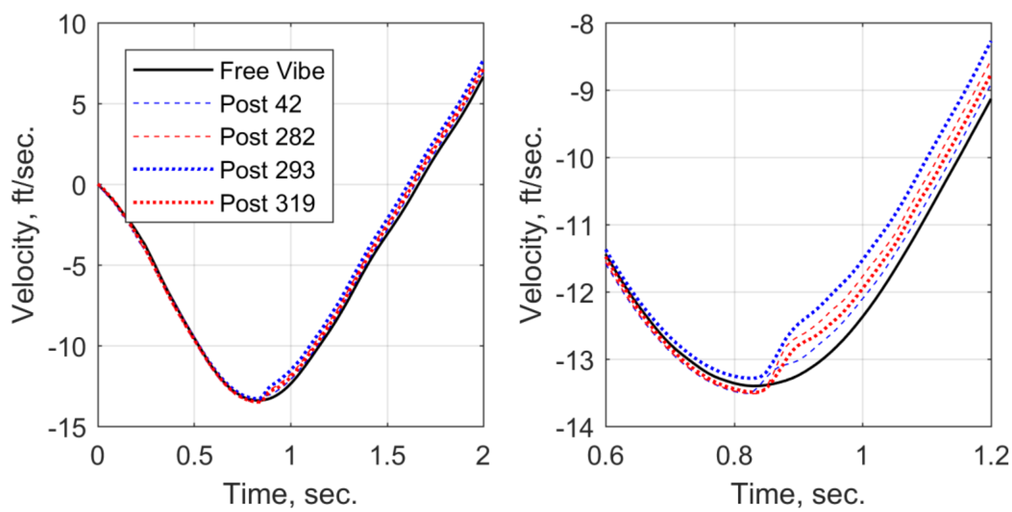
Post #	Treatment	Preservative Penetration (mm)[a]	Retention (kg/m^3)[b]	Post Area Decay (%)	Fungal Isolation Frequency (%)
58	CCA	**23.4**	**10.08**	20	40
76	CCA	**18.4**	**8.23**	2	60
78	CCA	**14.1**	4.86	0	0
124	CCA	**21.9**	2.35	0	0
230	CCA	**10.3**	5.78	25	20
257	CCA	**12.0**	1.86	0	0
271	CCA	**15.5**	3.15	15	0
285	CCA	**12.0**	2.17	5	0
320	CCA	**25.0**	**8.88**	30	20
323	CCA	**22.1**	2.53	75	70
W324	CCA	**24.6**	6.71	15	60
385W	CCA	**22.2**	**8.08**	5	0
420	CCA	**11.9**	7.81	10	20
178	Penta	**35.1**	7.28	0	0
197	Penta	**24.0**	3.60	0	0

[a] Values are in bold type are over the minimum 10 mm penetration for highway guardrail posts.
[b] Values in bold type are over the minimum 8.0 kg/m^3 retention for highway guardrail posts.

Impact Resistance of Decayed Posts

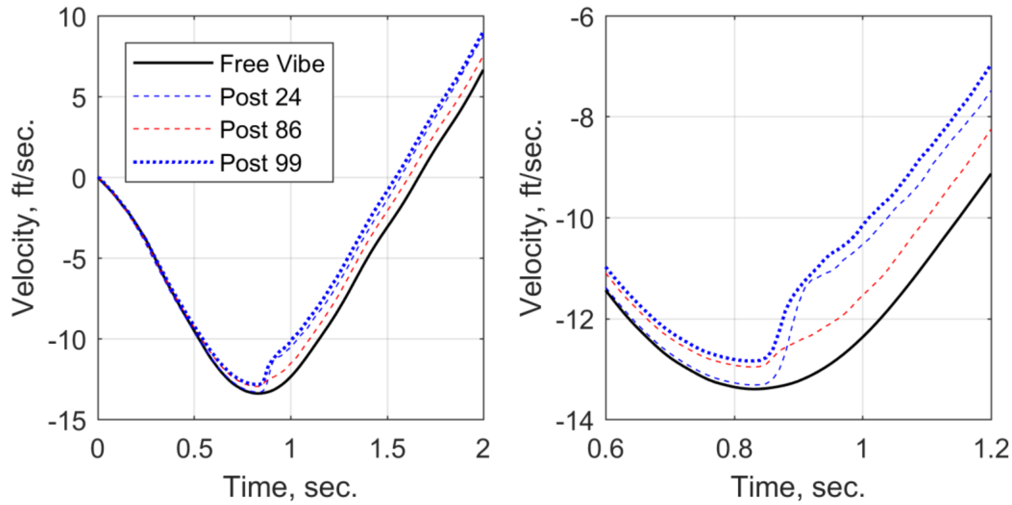
The impact resistance of the decayed posts was determined using both methods described for calculating fracture energy. Of the 15 specimens tested, four had laboratory measured SWT velocities at the ground level between 0 – 20 in./µs, eight had SWT velocities at the ground level between 21-38 in./µs, and three had SWT velocities at the ground level greater than 38 in./µs. Post behavior comparisons are made between the four posts with low SWT velocities (0 – 20 in./µs), classified as severely decayed, and the three posts with SWT velocities greater than what would be expected for sound Hemlock (38 in./μs). The posts with velocities between 21 – 38 in./μs were classified as moderately decayed and their response was highly variable, as discussed later.

Figure 13 and 14 show the velocity response of the severely decayed and sound posts, respectively. It can be seen in Figure 13b that the average change in velocity immediately following impact was approximately 0.75 fps for the severely decayed posts. For the posts without noticeable decay, the average change in velocity immediately following impact was approximately 2.25 fps, or 3 times more than the severely decayed posts. This difference in the change in velocity shows that the decayed posts had less fracture energy than the sound posts.



(a) t = 0 – 2 seconds (b) t = 0.6 – 1.2 seconds

Figure 13. Pendulum velocity for posts with SWT velocities at the ground level between 0 and 20 in/μs

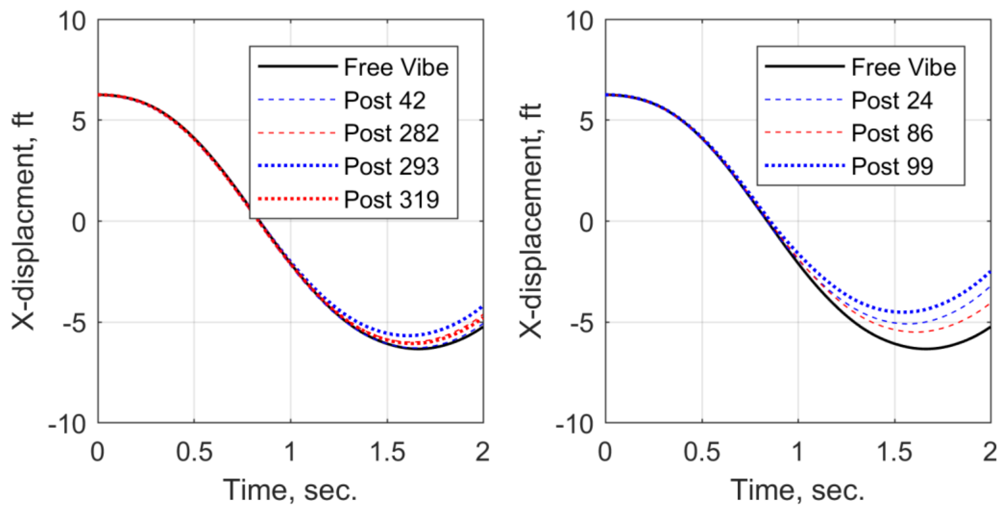


(a) t = 0 – 2 seconds (b) t = 0.6 – 1.2 seconds

Figure 14. Pendulum velocity for posts with SWT velocities at the ground level greater than 38 in/μs

Figure 15 shows the global x-displacement of the severely decayed and no noticeable decay posts respectively. Figure 15 demonstrates that the severely decayed posts did very little to slow down the pendulum, resulting in it achieving almost the same peak negative displacement as the free vibration tests. The posts without noticeable decay, shown in Figure 15b, had significantly less pendulum displacement after impact.

Figure 16 shows photographs of two fractured posts (Post 282 and Post 83) and their respective fracture energy, calculated using the difference in kinetic energy method. The interior of Post 282 was very soft and the wood crumbled with little effort, though the outside shell was relatively sound. Post 282 had a brash type of failure where the pendulum was able to break off the post with relative ease. Post 83 had no noticeable internal decay and the wood fibers can been seen to have participated more in the shearing failure of the post.



(a) SWT velocities 0-20 in/μs (b) SWT velocities >38 in/μs

Figure 15. Global x-displacement for severely decayed and sound posts

(a) Post 282 (FE_k = 1.06 k-ft) (b) Post 83 (FE_k = 2.84 k-ft)

Figure 16. Photographs of broken posts from testing.

Lastly, Figure 17 presents the calculated fracture energies of the 15 posts using both methods. It can be seen that there is a substantial difference in calculated fracture energy between the two methodologies for an individual post, though the same trends exist. The fracture energy of new, stress-graded Hemlock posts, as tested by Hancock and Mayer (1988), is shown in Figure 17 to be 3.35 k-ft. None of the 15 posts achieved this fracture energy. There could be several reasons for this, but the most likely one is the age of the posts (>20 years in service) since the sound posts were not far below the Hancock and Mayer (1988) test data. None of the posts having severe decay, or SWT velocities at the ground level less than 20 in./μs, were able to attain half the fracture energy of the new sound posts from Hancock and Mayer (1988). Only half of the moderately decayed posts had fracture energy greater than half of the Hancock and Mayer (1988) tests. Interestingly, two of the moderately decayed posts had approximately the same fracture energy as two of the posts with no noticeable decay.

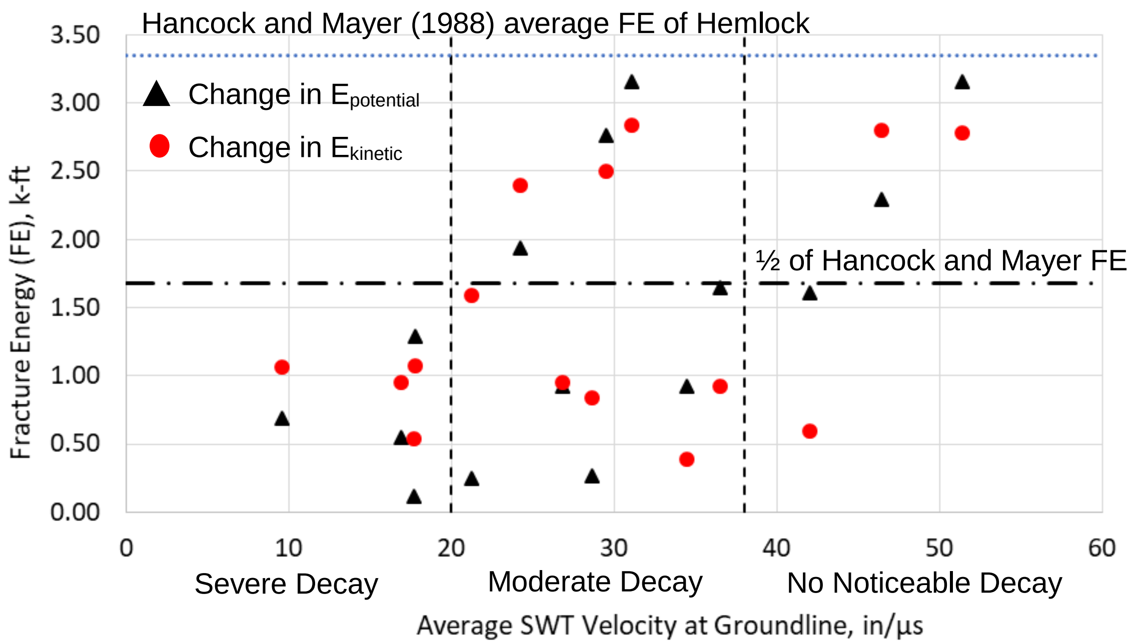


Figure 17. SWT velocity at ground level versus fracture energy

The impact testing results present a different conclusion on the effect of wood decay than previously conducted static bending tests, where even severe decay did not cause posts to lose their flexural capacity (Olszko and Bender 2015). In this case, the fracture energy of decayed posts was significantly less than that of sound posts. Table 5 presents the impact testing results for each post, including field and laboratory SWT velocity at the ground level, impact velocity, final velocity, peak negative pendulum displacement, and fracture energy calculated with both methods.

Table 5. Impact testing results

Post	Field SWT velocity (in./μs)	Laboratory Avg. SWT velocity at GL (in./μs)	Velocity at Impact (V_o), fps	Velocity after impact (V_f), fps	*Fracture Energy as ΔE_k, (FE_k), k-ft	Peak Pendulum Displacement, ($\delta_{x,max}$), in.	**Fracture Energy as ΔE_p, (FE_p), k-ft
282	29.4	9.6	13.5	12.8	1.06	-72.2	0.69
319	13.7	16.9	13.5	12.9	0.95	-73.1	0.55
302	20.0	21.2	13.7	12.7	1.59	-74.9	0.25
42	16.6	17.7	13.5	13.2	0.54	-75.6	0.11
291	15.2	28.6	13.6	13.1	0.84	-74.7	0.27
293	18.9	17.8	13.3	12.6	1.07	-68.4	1.29
254	11.8	34.5	13.3	13.0	0.39	-70.7	0.93
24	51.9	46.4	13.3	11.4	2.80	-61.36	2.29
66	19.8	24.3	13.4	11.8	2.39	-64.0	1.93
418	11.1	36.5	13.2	12.6	0.93	-66.0	1.64
33	23.5	26.8	13.5	12.9	0.95	-70.8	0.92
86	49.9	42.0	13.0	12.6	0.59	-66.3	1.93
300	53.1	29.5	13.2	11.5	2.50	-57.7	2.77
83	39.4	31.1	13.0	11.0	2.84	-54.5	3.15
99	31.2	51.4	12.8	10.8	2.79	-54.4	3.16

* Refer to Equation 6 for calculation of fracture energy as change in kinetic energy

** Refer to Equation 7 for calculation of fracture energy as change in potential energy

Conclusions

This study has confirmed that stress wave timing (SWT) remains the best option for non-destructive testing (NDT) and field evaluation of timber guardrail posts. As shown by Table 2, the next best non-destructive evaluation method was sounding and it was 87% accurate compared to SWT. All field evaluations were conducted during the summer months and therefore posts were relatively dry.

As shown by Table 3 and Figure 10, the highest timber decay risk location in the sample was found to be in Raymond, with a decay rate of approximately 38%. The inspection regions of Aberdeen and Naselle had the next highest decay rates of approximately 30%. Additionally, Figure 11 and 12, demonstrate that Scheffer climate index is likely a good predictor of high decay rates. For posts in regions with climate index less than 40, virtually no cases of decay were found during field evaluations.

Based on material testing conducted at Oregon State University, it can be assumed with reasonable certainty that the posts inspected were Hem-fir, though it cannot be determined if species grouping had any significant role in the high rates of decay. The preservative penetration was within the AWPA Standard minimum value of 10mm for all sample posts. Therefore, lack of preservative penetration is likely not a factor causing high rates of decay. However, the posts had poor preservative retention rates, with 73% of the tested posts having lower than the AWPA Standard value of 8.0 kg/m^3. Previous research has shown that low preservative retention rates can be correlated to higher rates of timber decay (Love et al. 2014, Sinha et al. 2015). Furthermore, preservative retention is not something that reduces due to exposure to field conditions, therefore posts likely had poor preservative retention levels during their entire service life, which may have had a significant increase in the decay rate.

The pendulum impact testing confirmed that wood decay significantly decreases the fracture resistance of the guardrail posts as compared to posts without decay. This is in contrast from conclusions made in the previous study by Olszko and Bender (2015), which were based on pseudo-static flexural tests of decayed timber posts compared to AASHTO standards on minimum bending strength. Based on the impact testing results, severe to moderate decay of the post can reduce its impact fracture resistance by more than 50%.

Recommendations/Application/Implementation

It is recommended that any inspection program developed for timber guardrail posts should utilize the SWT device. The prototype by Metriguard Inc. delivered to WSDOT at the conclusion of the Olszko and Bender (2015) study was successfully utilized during the field investigations in this study. Depending on the scale of such a program, WSDOT may acquire additional SWT devices from Metriguard, Inc for this purpose. Several other recommendations that can be supported by the data of this study are:

1. In the event that SWT inspection is not feasible, sounding is the next best and only preferable option. Drilling was found to be only slightly more accurate at locating decayed posts than sounding, but is invasive which is not desirable. Visual inspection was not found to be very accurate and should not be used as a standalone method of inspection.
2. Any post inspections performed using the SWT should use the following procedure:
    a. Test velocity at 15 in. above ground level
    b. Test velocity at ground level
    c. Classify post as decayed if: 1) velocities are more than 20% different and/or 2) ground level velocity is less than 38 in./μs for Hem-fir.
3. Any post inspection program should focus on regions with climate index greater than 40. Inspection of posts in areas with climate index less than 40 found

virtually no decayed posts. WSDOT's time and effort would be more efficiently utilized by focusing on regions with higher climate index.

4. Where wood posts are specified in construction or maintenance, it may be prudent to specify a minimum AWPA treatment category based on climate index of the installation region and ensure posts are certified by an accredited agency. Recommendations are as follows:

    a. For climate index greater than 60, specify treatment category UC4C (extreme duty for ground contact) for newly acquired batches of treated timber posts. This fits within the ALSC recommendations for critical structural components exposed to severe decay areas.

    b. For all other areas, specify treatment category UC4A (general use for ground contact) for newly acquired batches of treated timber posts.

    c. Newly acquired batches of treated timber posts should be inspected by an ALSC accredited agency and have the typical quality mark to ensure that preservative penetration and retention levels meet the AWPA specified minimums for their respective treatment category. Only three agencies are accredited by ALSC: 1) Bode Inspection, Inc., 2) Southern Pine Inspection Bureau, and 3) Timber Products Inspection.

5. Apply the results described in this report, especially the advantages of SWT technology and associated procedures, as well as the physical testing results of decayed posts, to inform decisions related to the management of existing guardrail systems that involve wood posts.

Acknowledgements

The authors express their appreciation to the personnel of the Simpson Strong-Tie Research and Structural Testing Laboratory, Bob Duncan and Scott Lewis, for their support in the setup and testing of the pendulum testing device. The authors would also like to recognize the contribution of Colin Lambie for his assistance during impact testing. Lastly, the authors would like thank Bradley Manchas of WSDOT for his guidance as technical monitor.

References

American Wood Council (AWC). (2015). *National Design Specification for Wood Construction with Commentary (NDS).* AWC, Leesburg, VA.

American Wood Protection Association. (2017). *Standard U1: Use Category System: User Specification for Treated Wood.* AWPA Book of Standard, AWPA, Birmingham, AL.

Brashaw, B. K., Vatalro, R. J., Wacker, J. P., and Ross, R. J. (2005). Condition Assessment of Timber Bridges: 2. Evaluation of Several Commercially Available Stress Wave Tools. *Gen. Tech. Rep. FPL-GTR-160.*, Madison, WI: USDA, Forest Products Laboratory.

Cappellazzi, J. and Morrell, J.J. (2018). Condition of section cuts from in service guardrail posts. *Report submitted to WSU*, Oregon State University, Corvallis, OR.

Emerson, R., Pollock, D., McLean, D., Fridley, K., Ross, R., and Pellerin, R. (2002). Ultrasonic Inspection of Large Bridge Timbers. *Forest Products Journal*, Forest Products Society, 52(9), 88-95.

Gabauer, D. J., Kusano, K. D., Marzougui, D., Opiela, K., Hargrave, M., and Gabler, H. C. (2010). *International Journal of Impact Engineering*, 37, 1121-1137.

Hancock, K. L. and Mayer, J. B. (1988). An Investigation of the Suitability of Great Lake States Timber Species for Guardrail Posts. *Report No. FHWA/MI-88/1*, Lansing, MI: MIDOT.

Hoyle, R. J. and Pellerin, R. F. (1978). Stress Wave Inspection of a Wood Structure. *Proc. of the 4th Symposium on Nondestructive Testing of Wood.* Pullman, WA: Washington State University: 33-45.

Love, C., Clauson, M., Sinha, A., and Morrell, J.J. (2014). Condition of chromated-copper-arsenate treated hem-fir guardrail post after 20 years in service in western Washington State. *Journal of Materials in Civil Engineering*, 26(1), 160-166.

NOAA. National Center for Environmental Information, accessed: April 2018. <https://gis.ncdc.noaa.gov/maps/clim/normals?&extent=-18336712.864029393:1154504.8752017636:-5969813.183717445:7739096.239798237&srid=102100>.

Olszko, A. A. and Bender, D. (2015). Identification of Test Methods for Determining Wood Guardrail Post Integrity. *Report No. WA-RD 843.1*, Olympia, WA: WSDOT.

Plaxico, C. A., Patzner, G. S., and Ray, M. H. (1998). Finite-Element Modeling of Guardrail Timber Posts and the Post-Soil Interaction. *Transportation Research Record*, 1647, Paper No. 98-0792.

Plaxico, C. A. and Ray, M. H. (2015). Effects of Guardrail Posts Deterioration on Crash Performance of Wood Post W-Beam Guardrails. *Proc. of the 94th Annual Meeting of the Transportation Research Board*, January 2015, Paper No. 15-2833.

Ross, R. J. and Pellerin, R. F. (1994). Nondestructive Testing for Assessing Wood Members in Structures: A Review. *Gen. Tech. Rep. FPL-GTR-70*, Madison, WI: USDA, Forest Products Laboratory.

Scheffer, T. C. (1972). A climate index for estimating potential decay in wood structures above ground. *Forest Products Journal*. 21(10): 25–31.

Sinha, A., J.J. Morrell, and M. Clausen. (2015). Use of acoustic assessment to detect decay and assess condition of wooden guardrail posts. *Forest Products Journal*, 64(7/8), 314-319.

American Lumber Standard Committee, Incorporated®

T.F. Brodie, Chairman
L.N. Belden, Vice Chairman
L.N. Belden, Treasurer
D.E. Kretschmann, President

7470 New Technology Way, Suite F
Frederick, Maryland 21703
Telephone: 301.972.1700
Fax: 301.540.8004
E-Mail: alsc@alsc.org

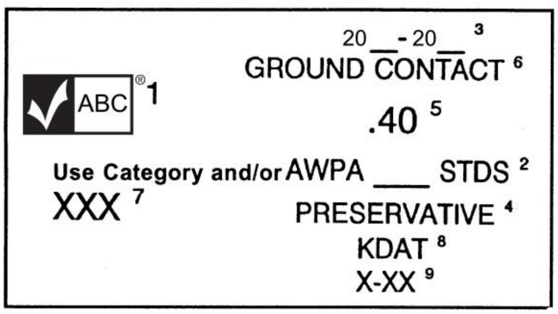
ACCREDITED AGENCIES FOR SUPERVISORY AND LOT INSPECTION OF PRESSURE TREATED WOOD PRODUCTS

January 2018

(this list supercedes all previous lists)

Agencies Accredited by the Board of Review of the American Lumber Standard Committee, Incorporated and Typical Quality Marks

Interpreting a Quality Mark



1 – The identifying symbol, logo, or name of the accredited agency in conjunction with AWPA required check-mark logo
2 – The applicable American Wood Protection Association (AWPA) standard and Use Category.
3 – The year of treatment if required by AWPA Standard / Use Category.
4 – The preservative used, which may be abbreviated.
5 – The preservative retention.
6 – The exposure category (e.g. Above Ground, Ground Contact, etc.).
7 – The company name and location of home office; or company name and number; or company number.
8 – If applicable, moisture content after treatment.
9 – If applicable, length, and/or class.

As specified below for particular agencies, some or all of the following American Wood Protection Association use-category standards are used by American Lumber Standard Committee, Incorporated accredited agencies which supervise facilities which pressure treat wood products:

Service Conditions for AWPA Use Category Designations

USE CATEGORY	SERVICE CONDITIONS	USE ENVIRONMENT	COMMON AGENTS OF DETERIORATION	TYPICAL APPLICATIONS
UC1 INTERIOR/ DRY	**Interior construction Above Ground Dry**	Continuously protected from weather or other sources of moisture	Insects only	Interior construction and furnishings
UC2 INTERIOR/ DAMP	**Interior construction Above Ground Damp**	Protected from weather, but may be subject to sources of moisture	Decay fungi and insects	Interior construction
UC3A ABOVE GROUND Protected	**Exterior construction Above Ground Coated & rapid water runoff**	Exposed to all weather cycles, not exposed to prolonged wetting	Decay fungi and insects	Coated millwork, siding and trim

UC3B ABOVE GROUND Exposed	**Exterior construction Above Ground Uncoated or poor water run-off**	Exposed to all weather cycles including prolonged wetting	Decay fungi and insects	Decking, deck joists, railings, fence pickets, uncoated millwork
UC4A GROUND CONTACT General Use	**Ground Contact or Fresh Water Non-critical components**	Exposed to all weather cycles, normal exposure conditions	Decay fungi and insects	Fence, deck, and guardrail posts, crossties & utility poles (low decay areas)
UC4B GROUND CONTACT Heavy Duty	**Ground Contact or Fresh Water Critical components or difficult replacement**	Exposed to all weather cycles, high decay potential includes salt water splash	Decay fungi and insects with increased potential for biodeterioration	Permanent wood foundations, building poles, horticultural posts, crossties & utility poles (high decay areas)
UC4C GROUND CONTACT Extreme Duty	**Ground Contact or Fresh Water Critical structural components**	Exposed to all weather cycles, severe environments extreme decay potential	Decay fungi and insects with extreme potential for biodeterioration	Land & Freshwater piling, foundation piling, crossties & utility poles (severe decay areas)
UC5A MARINE USE Northern Waters	**Salt or brackish water and adjacent mud zone Northern waters**	Continuous marine exposure (salt water)	Salt water organisms	Piling, bulkheads, bracing
UC5B MARINE USE Central Waters	**Salt or brackish water and adjacent mud zone NJ to GA, south of San Francisco**	Continuous marine exposure (salt water)	Salt water organisms Including creosote tolerant *Limnoria tripunctata*	Piling, bulkheads, bracing
UC5C MARINE USE Southern Waters	**Salt or brackish water and adjacent mud zone South of GA, Gulf Coast, Hawaii, and Puerto Rico**	Continuous marine exposure (salt water)	Salt water organisms Including *Martesia, Sphaeroma*	Piling, bulkheads, bracing

*** For additional information concerning the AWPA Use Category treatment requirements contact the American Wood Protection Association, P.O. Box 361784, Birmingham, AL 35236-1784 (Telephone 205.733.4077, Fax 205.733.4075, e-mail: email@awpa.com, url: www.awpa.com).

As specified in the following tables, some or all of the following preservatives are used:

CCA	- chromated copper arsenate
ACZA	- ammoniacal copper zinc arsenate
ACC	- acid copper chromate
ACQ	- alkaline copper quat.
CuN	- copper nahpthenate
PCP	- pentachlorophenol
CR	- creosote and/or solutions
SBX	- borates
CA	- copper azole
CX	-copper HDO
KDS	-alkaline copper betaine
EL2	-DCOI + Imidacloprid
PTI	-propiconazole tebuconazole imidacloprid
MCA	- micronized copper azole

KEY TO THE FOLLOWING TABLES

1	- sawn material and plywood
2	- plywood only
3	- sawn material only
R	- round commodities
SP	- southern pine
RP	- red pine
PP	- ponderosa pine
HF	- hem-fir
DF	- coastal Douglas fir
LP	- lodgepole pine
WH	- western hemlock
RDP	- radiata pine
CP	- caribbean pine
EWP	- eastern white pine
JP	- jack pine

ACCREDITED AGENCY AND ADDRESSES

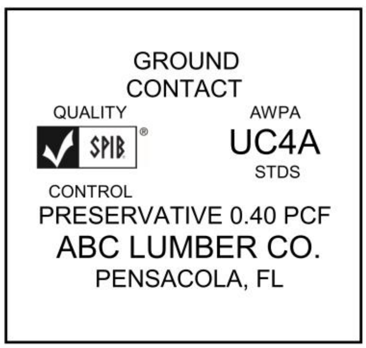
TYPICAL QUALITY MARK

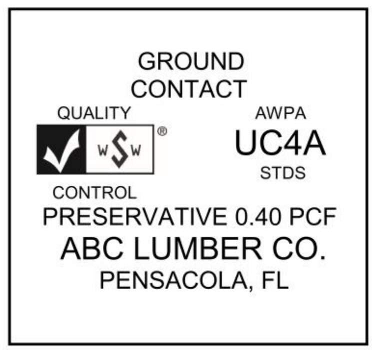
TABLE OF COMMODITIES, BY SPECIES AND PRESERVATIVE
(see key)

Bode Inspection, Inc.
P.O. Box 307
Beaverton, OR 97075-0307
503.590.3555
503.590.2802 (f)
e-mail: bodeins@comcast.net

	HF	DF	WH
CCA	1	1,R	R
ACZA	1	1,R	R
ACC	1	1,R	R
ACQ	1	1,R	
CuN	1	1,R	R
PCP	1	1,R	R
CR	1	1,R	R
CA	3	1	3
SBX	1	1	1

Southern Pine Inspection Bureau
4555 Spanish Trail
Pensacola, FL 32504
850.434.5011
850.434.5388 (f)
e-mail: spib@spib.org





ALL AWPA APPLICABLE SPECIES	
CCA	1,R
PCP	R
CR	R
ACQ	1
ACZA	1
ACC	1
SBX	1
CA	1,R
EL2	1
PTI	1
KDS	1,R
MCA	1,R

Southern Pine Inspection Bureau maintains a laboratory accredited for the analysis of wood samples pressure treated with the following preservative(s): CCA, ACC, ACZA, SBX, PCP, CR, CA, MCA, ACQ. EL2, PTI, and KDS.

Timber Products Inspection
P.O. Box 919
Conyers, GA 30012
770.922.8000
770.922.1290 (f)
e-mail: jwilliams@tpinspection.com

ALL AWPA APPLICABLE SPECIES	
CCA	1,R
ACZA	1,R
ACC	1,R
ACQ	1,R
CuN	1,R
PCP	1,R
CR	1,R
SBX	1
CA	1,R
CX	1
EL2	1
PTI	1
KDS	1,R
MCA	1,R

Timber Products Inspection maintains a laboratory accredited for the analysis of wood samples pressure treated with the following preservative(s): CCA, ACZA, ACC, ACQ, CuN, PCP, CR, SBX, CA, MCA, CX, EL2, PTI, and KDS.